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# Petrology of the Norphlet and Smackover Formations (Jurassic), Clarke County, Mississippi.

Calvin Lee Badon

*Louisiana State University and Agricultural & Mechanical College*

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PETROLOGY OF THE NORPHLET AND SMACKOVER FORMATIONS  
(JURASSIC), CLARKE COUNTY, MISSISSIPPI

A Dissertation

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy

in

The Department of Geology

by  
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## ABSTRACT

The Late Jurassic Norphlet and Smackover Formations are entirely subsurface units in the conterminous United States and are known only from data obtained from deep wells. In Clarke County, Mississippi, the Norphlet Formation consists of nonfossiliferous terrigenous clastics 50 to 400 feet thick and the overlying Smackover Formation consists of carbonate rocks 600 to 1000 feet thick. The petrologic analysis of these subsurface units is based on conventional cores and rotary drill cuttings which provide the basic data for definition of the various lithofacies and reconstruction of their depositional environments.

The Norphlet Formation which overlies the Louann evaporites (Middle to Late Jurassic) includes three lithofacies, a basal black shale facies, a middle red siltstone facies, and an upper quartz sandstone facies. The black shale and red siltstone facies represent supratidal to continental deposits which prograded southward as the Louann evaporite sea withdrew. The upper quartz sandstone facies represents deposition along a low-lying desert coast and includes both subaqueous shoreline sands and eolian sands.

The overlying Smackover Formation is subdivided into upper and lower members, each of which contain several

carbonate lithofacies. The lower member facies are predominantly carbonate mudstones and were deposited in a broad, very restricted, shallow coastal plain in which carbonate sediment production essentially kept pace with basin subsidence. The upper member lithofacies represent the first evidence of widespread open marine conditions. From the base of the upper member to the top, the carbonate facies represents a classic regressive sequence with progressive shoaling and continuous basinward progradation of environments. The nodular anhydrite in the basal part of the overlying Buckner Formation is the supratidal equivalent of the Smackover marine carbonates. The oölite and superficial oölite facies which occur near the top of the Smackover Formation has primary depositional interparticle porosity and together they form the principal oil and gas reservoirs in the Jurassic sequence. These initially porous sediments were cemented during burial by several types of calcite and dolomite cements in what is considered to be sequentially distinct stages of cementation. These cement types are described and the sequence of progressive cementation is outlined.

The Louann-Werner evaporite sequence forms the substratum upon which the Norphlet and Smackover rocks were deposited. During deposition of the overlying strata, the salt flowed in response to increasing overburden pressure resulting in the formation of salt cored anticlines. The earliest upward movement of the underlying salt mass appears

to have occurred during deposition of the lower Smackover (400-700 feet overburden) and during deposition of the upper Smackover and lower Buckner (1000 to 1500 feet overburden), the salt structures had their maximum upward movement.

## INTRODUCTION

Rocks of Late Jurassic age comprise a thick sequence of strata along the northern edge of the Gulf Coast Geosyncline, extending from Florida on the East to Mexico on the West. In the conterminous United States, these rocks are entirely subsurface units and are known only from data obtained from geophysical well logs, rotary drill cuttings, and conventional cores. The Late Jurassic rock-stratigraphic units are, in ascending order, the Norphlet Formation, the Smackover Formation, the Buckner Formation, and the Cotton Valley Group. Of these, only the Norphlet, Smackover, and the lower part of the Buckner Formation are included in this study.

In Mississippi, Jurassic deposition was largely controlled by a local structural feature, the Interior Mississippi Salt Basin. The basin is defined by the presence of the Louann Salt (Middle to Late Jurassic, Kirkland and Gerhard, 1971) which forms a continuous substratum upon which the Late Jurassic rocks were deposited. During subsequent burial, the underlying salt flowed in response to increased overburden pressure, forming diapiric salt domes and salt-cored anticlines (Hughes, 1968). The paleoenvironments of deposition and the possible effects of penecontemporaneous salt movement on these sedimentary environments are fundamental, not only to reconstruction of the history

of the basin, but also to exploration for the deeply buried oil and gas reserves contained in these rocks.

### Purpose

Considerable controversy has centered around the physical stratigraphy and depositional history of the Late Jurassic rocks in the Gulf area. Much of the difficulty arises from the necessity of using geophysical well logs and drill cuttings for definition of rock-stratigraphic units. As a result, facies relations between units which require detailed petrologic information is seldom considered. The analysis of specific depositional environments, based on modern analogs, is generally not applied to subsurface rocks because of the limited data available. Unfortunately, the petroleum geologist is all too often forced into treating the rock section as successive "layers" in a geochronologic sequence, and log correlations as time-stratigraphic boundaries.

The principal objectives of this study are to define the various lithofacies within the Norphlet Formation, Smackover Formation, and lower member of the Buckner Formation, to establish the interrelationships between these units and to reconstruct their depositional environments in the framework of a logical depositional history based on current sedimentological concepts. This work is the first attempt to study systematically the petrogenesis of these rocks by using thin-sections made from drill cuttings

and conventional cores. Earlier published accounts of the subsurface Jurassic have concentrated primarily on regional stratigraphic problems based on examination of drill cuttings in reflected light (Dinkins and Oxley, 1968).

A special section on structure and depositional history is included in this study in order to determine the effect of penecontemporaneous salt dome growth on deposition of the late Jurassic rocks. To this end, isopach maps of the individual members of each formation were constructed. However, the structure is treated only to the extent that it relates to the depositional history of the area. A more complete analysis of the post-Jurassic structure would require gravity and seismic data and is beyond the scope of this study.

### Study Area

The study area is situated on the northeast flank of the Mississippi Salt Basin and covers an area 18 miles long and 12 miles wide along the western edge of Clarke County, Mississippi (Figure 1). This area was selected for study because it includes the most prolific part of the Norphlet-Smackover producing trend in the eastern Gulf region, and as such, has the highest density of wells. In January, 1972, nine fields were producing from this sequence within the study area, all of which were discovered during the period 1967 to 1971.

The Goodwater, East Nancy, and Harmony Fields were

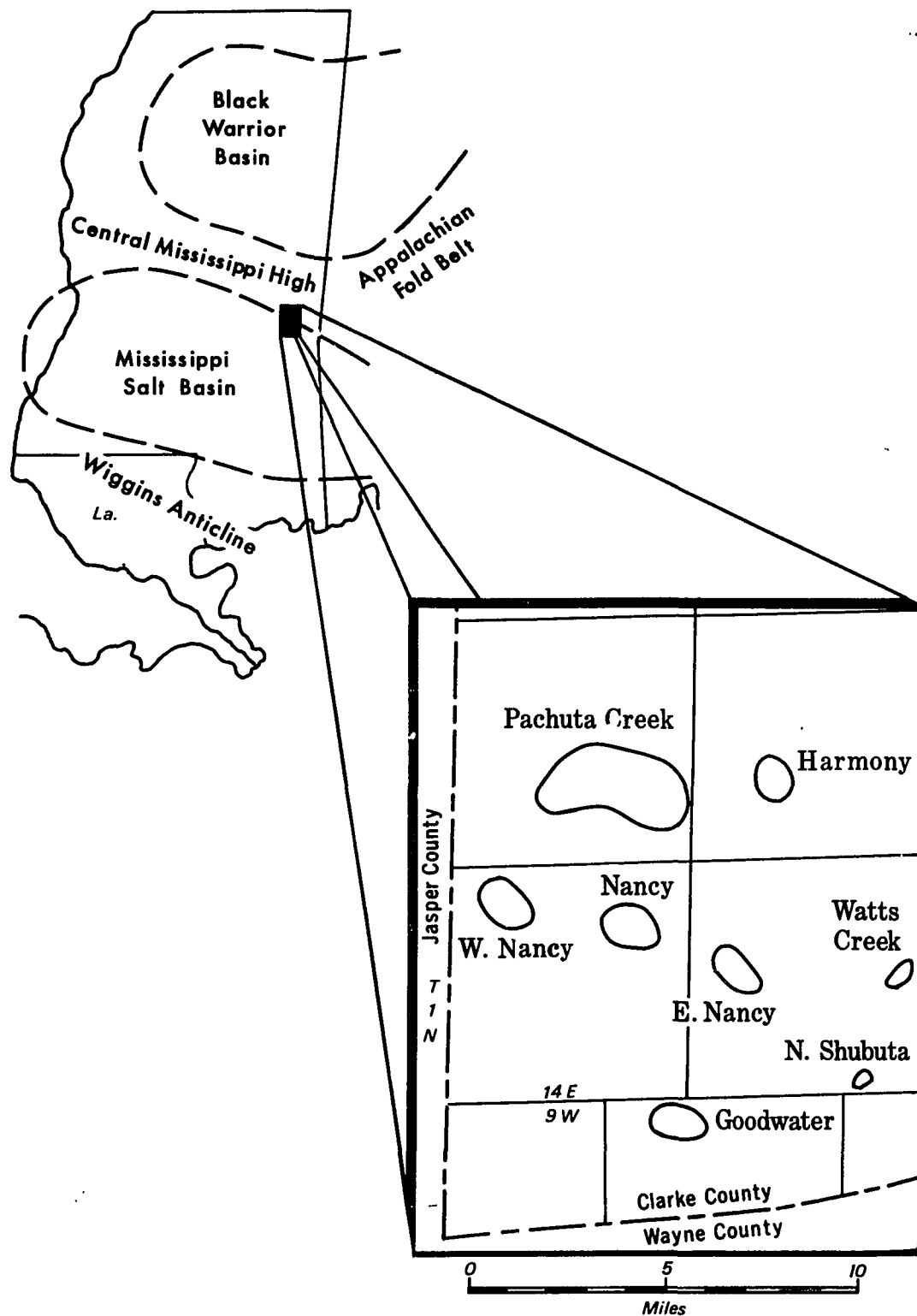


FIGURE 1. Study Area and Location of Smackover Field

selected for detailed study because they are thought to be situated perpendicular to the Smackover shoreline. All of the available conventional cores from these three fields were used to establish the basic petrologic framework. Cores and drill cuttings from adjacent areas were used primarily to complete the stratigraphic sequence. Isopach maps which reflect salt dome growth concurrent with deposition were constructed to cover the entire study area.

### General Geology

#### Tectonic Setting

Clarke County, Mississippi, is located along the northeast flank of the Mississippi Salt Basin, one of several smaller depressions developed within the northern boundary of the Gulf Coast Geosyncline. The basin was probably initiated during Permian or Triassic time, as the oldest deposits in the basin are reported to be Eagle Mills continental clastics (Dinkins, 1968). Although these rocks have not been dated in Mississippi, similar deposits in Southern Arkansas were assigned a late Triassic age (Scott, et al., 1961) based on plant remains. Clastic deposition was followed by deposition of the Werner-Louann evaporite sequence (Middle Jurassic ?) which represents the first major incursion of marine waters into the basin. The up-dip limit of this evaporite sequence to the north and the thinning of the salt over the area of the Wiggins Anticline to the south essentially defines the boundaries of the Mississippi Salt



Basin (Figure 1). Basin subsidence was accompanied by salt flowage and minor faulting which represents the principle structural modifications in the basin (Hughes, 1968). The up-dip limit of the Louann Salt occurs near the northern boundary of the study area and from here it is reported by Hughes to form a thick wedge extending southwestward into the center of the basin. Salt structures are thought to be controlled by the primary thickness of the salt such that across the study area the morphology of the salt structures change from low relief swells on the north to high relief anticlines on the South. The time of growth of these structures and the degree to which they have affected sedimentation will be treated in the section Structure and Depositional History.

### Stratigraphy and Nomenclature

Considerable controversy has centered around the nomenclature of Upper Jurassic rocks in Mississippi, both in the literature and by petroleum geologists working in the area. The formational nomenclature used in this study is considered to follow the original usage proposed for the Norphlet (Hazzard, et al., 1947), Smackover (Weeks, 1938), and Buckner (Weeks, 1938) Formations in the subsurface of Union County, Arkansas. The study area located on the north flank of the geosyncline in Eastern Mississippi appears to be generally along depositional strike with the type sections. The sedimentary sequence therefore is sufficiently similar

in lithologic character to justify using the same nomenclature.

Two previous studies of the upper Jurassic stratigraphy of Mississippi and Southwest Alabama are notable: Dickinson, 1962; and Dinkins, et al., 1968. The stratigraphic nomenclature and formational boundaries used in this study differ from the previous workers as shown in Figure 2.

### Norphlet Formation

The Norphlet Formation as defined by Hazzard, Spooner, and Blanpied (1947) at the subsurface type section in Union County, Arkansas, consists of red and gray shales interbedded with red and gray sandstones. As used here, the Norphlet Formation includes all of the terrigenous clastics overlying the Louann salt and underlying carbonate rocks of the Smackover Formation. This usage is thought to be consistent with that proposed by Hazzard, Spooner, and Blanpied to include strata overlying the Louann Salt and underlying the Smackover Formation. The Norphlet Formation of this study is used in the same sense as Dickinson, 1962 (Figure 2). However, the formational boundaries differ from that used by Dinkins, et al., 1968. The Norphlet Formation of these workers is probably equivalent only to the lower member of this study, and the upper member, as used here, was referred to as lower Smackover sand by Dinkins, et al. 1968 (Figure 2).

K. Dickinson, 1962			Dinkin and Oxley et. al. 1968		This Report	
Ivy Formation			Haynesville Formation		Upper Member	
Buckner Formation					Lower Member	
Smackover Formation			Upper Member		Upper Member	
					Lower Member	
			Lower Member		Lower Member	
Norphlet Formation			Lower Member		Upper Member	
					Lower Member	
			Louann-Werner		Louann-Werner	

FIGURE 2. Nomenclature of Upper Jurassic Norphlet Formation, Smackover Formation, and Buckner Formation in Eastern Mississippi

The formation appears to be present at least along the northern edge of the Geosyncline from the panhandle of Florida to East Texas. In Mississippi, the Norphlet Formation extends beyond the up-dip limit of the Louann Salt to unconformably overlie older Mesozoic and Paleozoic rocks. The contact between the Louann and Norphlet Formations has been described as unconformable (Hazzard, et al., 1947), but physical evidence for unconformity in Mississippi is lacking. In down-dip areas to the south, very little is known of the Norphlet beds because of the greater depth of burial and the diapiric nature of the underlying salt. In these areas, wells are usually located over salt structures which by their diapiric activity cause the salt mass to move into a higher stratigraphic position above the level of the younger strata. Therefore, wells drilled over salt structures commonly bottom in diapiric salt, and the younger strata which overlie the salt along the flanks of the structure are missing from the stratigraphic section along the crest. In the central and southern parts of the Mississippi Salt Basin, the Norphlet Formation has not been reported, but may be present in the interdomal areas.

#### Smackover Formation

The Smackover Formation was originally defined by Weeks (1938) from Union County, Arkansas, and consists of a lower cryptocrystalline limestone or "dense lime," and an upper part which includes soft chalky limestone and

oolitic limestone. The Smackover Formation overlies the Norphlet Formation conformably except over salt structures where it rests upon diapiric salt. In up-dip areas where the Norphlet is absent, the formation unconformably overlies older rocks of Mesozoic and Paleozoic age.

The lower member commonly called the "brown dense lime" is the most persistent lithologic unit in the Smackover and generally can be recognized throughout the northern part of the Mississippi Salt Basin. In Jasper County, Mississippi, at the western edge of the study area, the lower unit is interbedded with gray terrigenous sandstones of the Norphlet Formation. This has caused some workers to consider the gray sandstones of the upper Norphlet as part of the Smackover Formation (Dinkins, et al., 1968).

The upper member of the Smackover Formation shows a greater diversity of lithologies and has been divided into upper and middle members by Dickinson (1962, 1968). Two extensive zones of detrital quartz sandstone are developed in the upper part of the formation, one centered in Madison County, Mississippi, and the other in Washington and Clarke Counties, Alabama (Dinkins, et al., 1968). A thick sequence of oolitic limestone which lies between these two clastic wedges is developed in Clarke and Wayne Counties, Mississippi, and Choctaw County, Alabama.

Very little information has been published on the down-dip lithology of the Smackover Formation. On the south flank of the basin in Stone County, Mississippi, the George

Vasen's Fee #1 penetrated 1,620 feet of carbonate rocks which were assigned to the Smackover Formation (Applin and Applin, 1953). To the east in Southwest Alabama, Dickinson (1962) reported a down-dip Smackover facies consisting of alternating beds of halite interbedded with anhydrite.

### Buckner Formation

The term Buckner Formation was first applied by Weeks (1938) to strata overlying the Smackover Formation in the subsurface of Union County, Arkansas. These rocks were described as consisting of an upper unit of red shale, a middle unit of red shale with nodules of anhydrite, and a basal unit consisting mainly of anhydrite with some stringers of red shale and dolomite. These units were subsequently included in the Haynesville Formation (Philpott and Hazzard, 1949) and the term "Buckner" was relegated to the lower anhydrite part of the original formation. Following the more recent work of Dickinson, 1968, and deBartolo, 1970, the Buckner Formation, as used here, includes all of the strata overlying the Smackover Formation and underlying the Cotton Valley Group (Swain, 1944). The Buckner Formation is divided into two informal members: an upper member that is predominantly shale with variable amounts of limestone and sandstone, and a lower member which is predominantly anhydrite. Only the lower member which overlies and is interbedded with the Smackover Formation is included in the present work.

The lower member of the Buckner Formation appears to be restricted generally to the north flank of the Mississippi Basin where it occurs as a band of variable width that extends from southwest Alabama through central Mississippi. A down-dip facies reported by Dinkins, et al., (1968) was described as mainly dense limestone and shale.

### Methods

The study materials are entirely from deep wells and include conventional cores, rotary drill cuttings, and geophysical well logs. The conventional cores are the most important, as they provide the basic petrographic data for definition and description of the lithofacies. Where cores are unavailable, thin sections made from rotary drill cuttings were used to supplement the study. Geophysical logs were used primarily for correlation purposes and secondarily to aid in defining lithology over intervals from which only drill cuttings were available. The use of subsurface materials for petrologic work presents some problems not normally encountered in the study of surface outcrops. For this reason, the manner in which these were used is described below. The procedures employed in the petrographic analysis of the conventional cores and drill cuttings are found in Appendix A.

## Conventional Cores

Conventional cores refer to the sample of rock retrieved by a hollow drilling bit which cuts and retains a section of the rock penetrated. All of the available cores from the Goodwater, East Nancy, and Harmony Fields were used in the study as well as selected ones from adjacent areas. A total of 29 cores from the Norphlet, Smackover, and Buckner Formations were examined, and approximately 550 thin sections were prepared for petrographic analysis. Table I lists these cores according to formation, well name, location, and sample interval. On the reference sections (Figure 9, 15, and 25) and stratigraphic cross sections (in pocket), the cored interval is indicated by brackets on the left side of the bore hole section.

Two problems were encountered which are inherent in the use of conventional cores. The first is that the measured depth of the core does not necessarily correspond to the measured depth of the electric log over the same stratigraphic interval. Consequently, the core must be shifted vertically to coincide with the more correct log depth. In most cases, a distinctive lithology in the core could be matched with its resistivity characteristics on the electric log. The amount of correction was occasionally measured in tens of feet and is indicated on the stratigraphic cross-sections. The second problem which imposes a more severe limitation pertains to the physical condition of the core itself. To facilitate handling, the cores are broken into



TABLE I  
CONVENTIONAL CORES

(Well Name)	(Location)	(Sample-Interval) (Measured Depth)
<u>NORPHLET FORMATION</u>		
Shell #1 Johnston	Goodwater Field	15602-15650
Getty #1 Masonite 18-8	E. Nancy Field	14301-14340
Getty #1 Allen 20-7	E. Nancy Field	14300-14320
Chevron #1 Hand "2"	Watts Creek Field	14377-14437
Exchange #1 Evans 35-1	N. Shubuta Field	14862-14918
<u>SMACKOVER FORMATION, LOWER MEMBER</u>		
Shell #1 Johnston	Goodwater Field	15266-15283
Getty #1 R.Williams 18-9	E. Nancy Field	14035-14144
Getty #1 Masonite 18-8	E. Nancy Field	14280-14301
Getty #1 Collins-Coleman 19-1	E. Nancy Field	14150-14206
Getty #1 Allen 20-3	E. Nancy Field	13995-14068
Getty #1 Allen 20-7	E. Nancy Field	14270-14300
Chevron #1 Hand "2"	Watts Creek Field	13834-13955
<u>SMACKOVER FORMATION, UPPER MEMBER</u>		
Shell #1 Johnston	Goodwater Field	14623-14655
Shell #1 Ulmer	Goodwater Field	14562-14596
Shell #1 Ruter	Goodwater Field	14623-14655
Shell #1 Thomas	Goodwater Field	14690-14778
Shell #3 Thomas	Goodwater Field	14630-14672
Getty #1 Masonite 17-3	E. Nancy Field	13590-13710
Getty #1 Masonite 18-8	E. Nancy Field	13509-13688
Getty #1 Coleman 18-5	E. Nancy Field	14565-14668
Getty #1 Allen 20-4	E. Nancy Field	13580-13635
Getty #1 Allen 20-7	E. Nancy Field	13525-13645
Getty #1 Masonite 20-70	E. Nancy Field	13561-13679
Dunbar #A-1 M.Kirkland 29-1	Harmony Field	12620-12679
Masonite #1 Masonite 20-6	Harmony Field	12522-12570
Masbacher #1 Bd. of Supv. 16-13	Harmony Field	13412-12440
Exchange #1 Evans 35-1	N. Shubuta Field	14207-14345
Chevron #1 Hand "2"	Watts Creek Field	13372-13472
Harris #1 Moore 10-2	WC/Sec.10, 3N-14E	11613-11675
Shell #1-Evans 26-6	Pachuta Creek Field	12828-12975
<u>BUCKNER FORMATION, LOWER MEMBER</u>		
Shell #1 Johnston	Goodwater Field	14545-14565
Getty #1 Masonite 14-4	Nancy Field	13347-13456

pieces several inches in length and then slabbed into halves or quarters and placed in boxes three to four feet long. Because often times the cores were not properly marked initially, the orientation and relative position of the core pieces within each box usually cannot be determined. In addition, individual beds which are thicker than the length of the core pieces could not be measured.

### Rotary Drill Cuttings

Drill cuttings are rock chips cut by a bit in the process of well drilling and are usually collected at intervals of ten to twenty feet. The cuttings are normally contaminated from cavings farther up the hole and consequently lithologic descriptions based on cuttings are interpretive. However, petrographic thin sections made from cuttings were found to be useful for those intervals that were not cored especially when used in conjunction with the geophysical well logs. The drill cuttings are usually collected at ten or twenty foot intervals and are considered to be a channel sample. The procedure in this study was to select five to ten representative chips from each sample which were imbedded in plastic and standard petrographic thin sections were made. The influence of uphole contamination is reduced significantly by a knowledge of the uphole lithologies and the expected in-place lithology as deduced from the geophysical logs. The rotary drill cuttings which were used are listed in Table II. On the reference sections and cross-sections,

TABLE II  
DRILL CUTTINGS EXAMINED

(Well Name)	(Location)	(Stratigraphic Interval)
Shell #1 Johnston	Goodwater Field	Buckner-Norphlet
Shell #2 Johnston	Goodwater Field	Buckner-Norphlet
Shell #3 Johnston	Goodwater Field	Buckner-Norphlet
Shell #2 Thomas	Goodwater Field	Buckner-Norphlet
Shell #3 Thomas	Goodwater Field	Buckner-Norphlet
Shell #1 McCarty	Goodwater Field	Buckner-Norphlet
Shell #1 Ulner	Goodwater Field	Buckner-Norphlet
Shell #1 Ruter	Goodwater Field	Buckner-Norphlet
Getty #1 Masonite 17-13	E. Nancy Field	Buckner-Norphlet
Getty #1 Masonite 14-14	Nancy Field	Buckner, Norphlet
Exchange #1 Evans 35-1	N. Shubuta Field	Norphlet
Chevron #1 Hand "2"	Watts Creek	Buckner-Norphlet
Getty #1 - Crook	Pachuta Creek Field	Norphlet
Harris #1 Evans 4-4	WC/Sec. 4 1N-15E	Buckner-Norphlet
Exchange #1 Bufkin 6-7	WC/Sec. 6 2N-15E	Buckner Norphlet
Harris #1 Moore 10-12	WC/Sec.10 3N-14E	Buckner-Norphlet
Sun #1 Board of Supervisor 16-13	WC/Sec.16 3N-15E	Buckner-Paleozoic

the intervals from which drill cuttings were examined are shown by a heavy solid line to the right of the bore-hole section.

### Geophysical Well Logs

The well logs used in this study are the Dual-Induction-Lateralog (DIL), the Compensated-Formation-Density Log (FDC), and the Sidewall Neutron Porosity Log (SNP). The DIL log was used primarily for correlation of strata between wells and for determining upper and lower lithologic boundaries. The FDC and SNP logs enabled lithologic determinations according to the cross-plot method suggested by Schlumberger Limited (1969). This interpretation is only an approximation of gross lithology and was used solely as an aid in selecting representative pieces from the drill cutting samples. For mapping purposes, an effort was made to utilize the geophysical logs from all the wells in the study area. In some cases, the logs could not be made available for this study, and these are indicated on the Structure Map (Plate V) and in Appendix D as NA (not available).

## NORPHLET FORMATION

The Norphlet Formation is a nonfossiliferous terrigenous clastic sequence composed of shales, siltstones, and quartz sandstones. Within the study area, three lithofacies can be defined: in ascending order these are a black shale facies, a red siltstone facies, and a quartz sandstone facies (Plate 1). These units are grouped into two informal members based principally on texture, an upper sandstone member and a lower member that consists of the black shale and red siltstones. This textural subdivision is convenient for mapping purposes because where drill cuttings and cores are unavailable, the members can be readily distinguished on the basis of the DIL and FDC logs. The upper member is particularly significant because it produces oil in the East Nancy and Prairie Branch Fields and carries shows of hydrocarbons in several other areas.

### Lower Member of the Norphlet Formation

#### Stratigraphic Relationships

The lower member consists of two distinctly different lithofacies, the basal black shale facies, and the overlying red siltstone facies. The Isopach Map (Figure 3) shows the thickness variations of the lower member within the study area. The member thins across the Pachuta Creek and Harmony Fields, but thickens to the south and reaches a maximum value of 160 feet in the Watts Creek Field area.

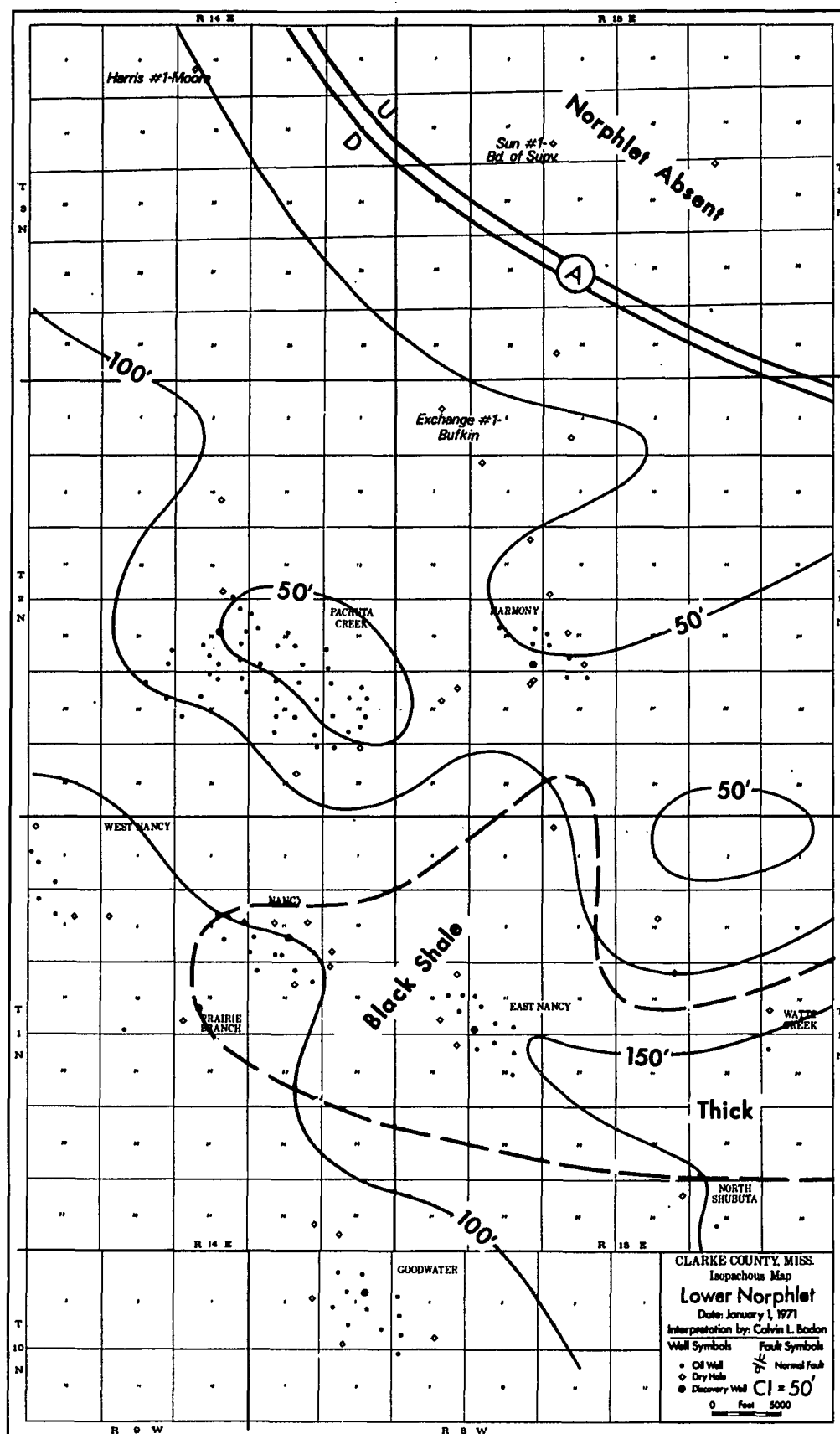


FIGURE 3. Isopach Map, Lower Member of Norphlet Formation.  
(Isopach Values in Appendix D) Dashed line indicates  
extent of Black Shale Facies.

This maxima trends E-W along a line extending from Watts Creek to East Nancy Field and possibly north of the Nancy Field.

The basal black shale facies is probably present only in the area of the Watts Creek, East Nancy, and Nancy Fields (Figure 3) where it has an average thickness of 30 to 40 feet. This facies was identified solely on the basis of drill cuttings (Appendix B1) and where they were not available, the presence or absence of the black shale facies could not be determined. The overlying red siltstone facies is present in every well which penetrated the section except the Sun #1 Board of Supervisors (WC/Sec. 16, 3N-15E) situated on the upthrown side of the "A" fault (Figure 3). In the Sun well, the Louann Salt is absent, and the well penetrated 90 feet of black phyllitic shale at total depth. The phyllitic shale is considered to be Paleozoic in age because of the low rank metamorphic appearance of the rock in thin sections. Between the phyllitic shale and the Smackover carbonates is 170 feet (10940-11110) of material that is completely unlike the Norphlet rocks to the south. In thin sections made from drill cuttings, these appear as fragments of calcite, hematitic shales, and argillaceous calcite. This unit is thought to be pre-Louann, and was assigned to the Eagle Mills Formation by Dinkins, et al., (1968). On the downthrown side of the fault, the red siltstone is relatively thin, but thickens rapidly on the south flank of the Harmony and Pachuta Creek structures.

## Petrology

### Black Shale Facies

The black shale facies was identified solely on the basis of drill cuttings (Appendix B1). During the initial stages of the study, it was difficult to distinguish because of contamination by gray shales from the uphole section. However, after the writer became more familiar with the uphole lithologies, fragments of the basal facies could be separated on the basis of darker coloration, fissility, and fresh appearance.

The black shale appears to be composed primarily of argillaceous material and is considered to be laminated.\* The majority of the fragments, however, appear nonlaminated which is thought to be due to unoriented fragments that are cut roughly parallel to bedding. The black coloration is probably due to carbonaceous material and where high concentrations are found, the thin sections are almost opaque to transmitted light. Silt size detritus is rare, but small mica-flakes and disseminated pyrite are fairly common. No evidence of fossils was observed, but it should be remembered that sampling was extremely meager.

### Red Siltstone Facies

The overlying red siltstone facies was cored in only one

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\*(The bedding terms used here are from Bouma, 1962; lamination =  $\leq$  0.5cm; fine bedded = 0.5-5.0cm; medium bedded = 5-20cm; thick bedded =  $>$  20cm.)



well, the Shell #1 Johnston, Goodwater Field (Plate 1). Near the upper part, the siltstone is laminated to fine bedded and interbedded with lenses of red sandstone with scour features. Below, the red siltstone grades into darker red silty mudstones and thin lenses of cross-laminated fine sandstones. Also small, oblong, white to pink anhydrite nodules (Appendix A4) are occasionally found in this zone.

This facies is composed primarily of angular silt-sized quartz and coarse mica flakes (0.100-0.200mm), with a very fine hematite matrix (Figure 4A). Laminations, where present, consist of alternating laminae of predominantly hematite and silt-sized quartz with interstitial hematite. The coarse mica is usually found in the silt laminae and is oriented roughly parallel to bedding. Anhydrite cement is also present in the silt laminae where the grains are packed (grain supported), but it rarely makes up more than ten percent of the interstitial material. In the mudstone units, silt sized quartz and mica commonly occur "floating" in the hematite matrix. The anhydrite nodules occur most frequently in the mudstone beds and consist of small (0.050-0.200mm) felty crystals, tightly packed with a subparallel fabric. These nodules are thought to be early diagenetic; that is, formed by displacive growth in soft sediment prior to lithification. However, the lack of stratification in the host rock prevents definite determination of the time of growth of these nodules. The interpretation is based primarily on the similarity of the internal texture of the polycrystalline

FIGURE 4. Photographs: Norphlet Formation

- A. Red Siltstone Facies. Angular silt-size quartz and mica alternating with hematite laminae.
- B. Red Sandstone Subfacies. Detrital dolomite (d) with zoned overgrowth and rounded quartz grains. The interstices are filled with hematitic detrital matrix.
- C. Homogeneous Grey Sandstone Subfacies. Porous protoquartzite impregnated with dark resin which fills the interstices.
- D. Homogeneous Grey Sandstone Subfacies. Large single crystal of dolomite cement (d) may be overgrowth on detrital dolomite nucleus.
- E. Homogeneous Grey Sandstone Subfacies. Fine grained protoquartzite with interstitial anhydrite cement.
- F. Close up of Figure 4-E showing quartz grains cemented by lath-shaped anhydrite crystals (a).

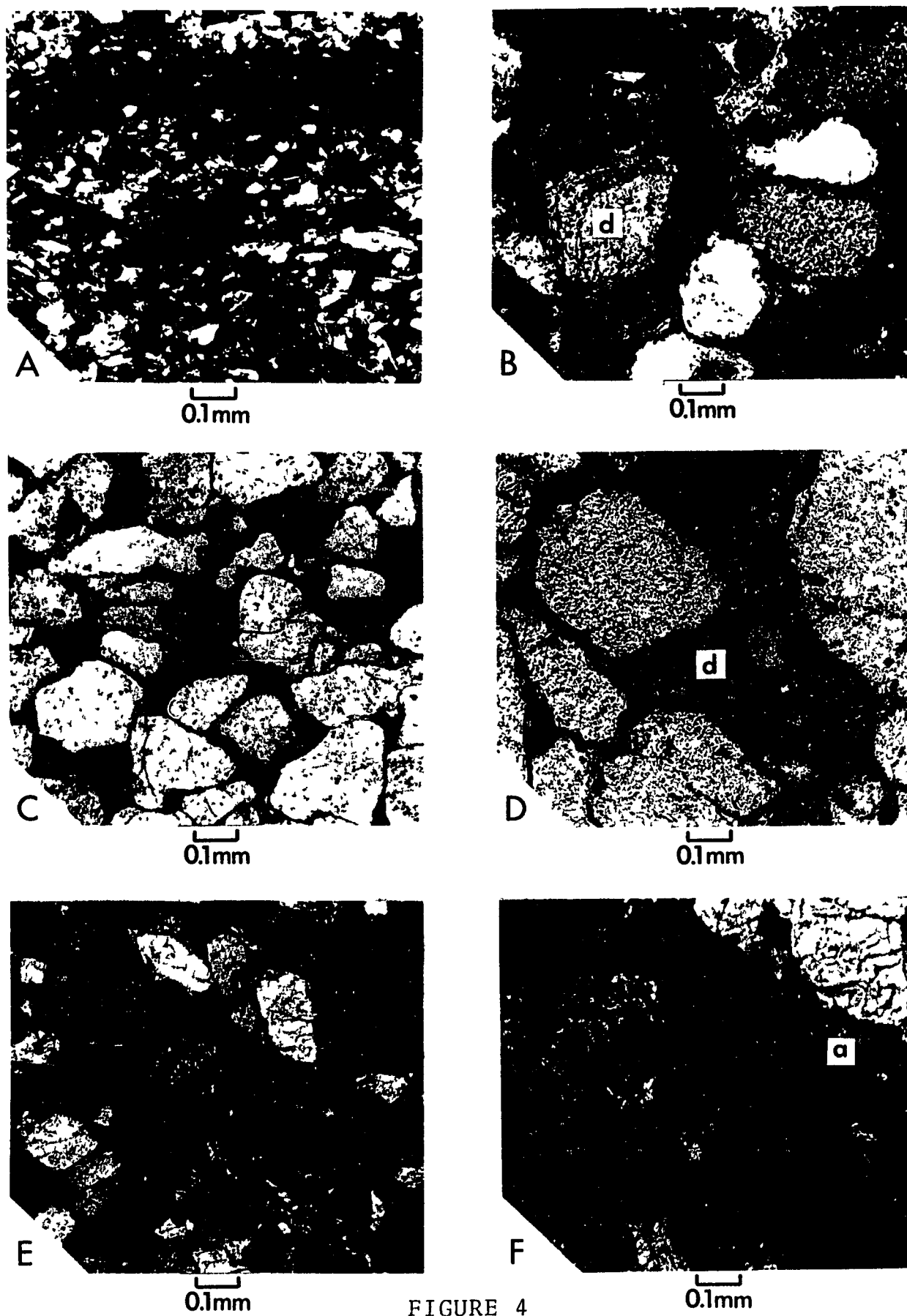


FIGURE 4

nodules with those found in the Smackover and Buckner Formations where they are demonstratively early diagenetic.

### Upper Member of the Norphlet Formation

#### Stratigraphic Relationships

Three subfacies can be distinguished within the upper member of the Norphlet based on composition and sedimentary structures: a lower red sandstone, a middle bedded grey sandstone, and an upper homogeneous grey sandstone (Plate 1). It should be noted, however, that the definition of these units is based on five conventional cores (Appendix B2), each representing only a part of the Norphlet sequence. Therefore, it is not known whether these three subfacies make up the entire Upper Norphlet, or that additional sandstone subfacies are present in the interval that was not cored.

Figure 5 is an Isopach Map of the upper member showing the thickness variation across the study area. The values shown with a plus sign, i.e. (+200) in Appendix D indicate that the well bottomed in the upper member, and consequently the isopach value represents a minimum thickness. The overall variation in thickness is similar to the lower member in that the unit is thin or absent across the Pachuta Creek and Harmony Fields and thickens rapidly along the Watts Creek, East Nancy, and Nancy Fields. In the north, the upper member of the Norphlet Formation appears to be absent from the Harmony and Pachuta Creek structures based primarily on the analysis of geophysical well logs. On the

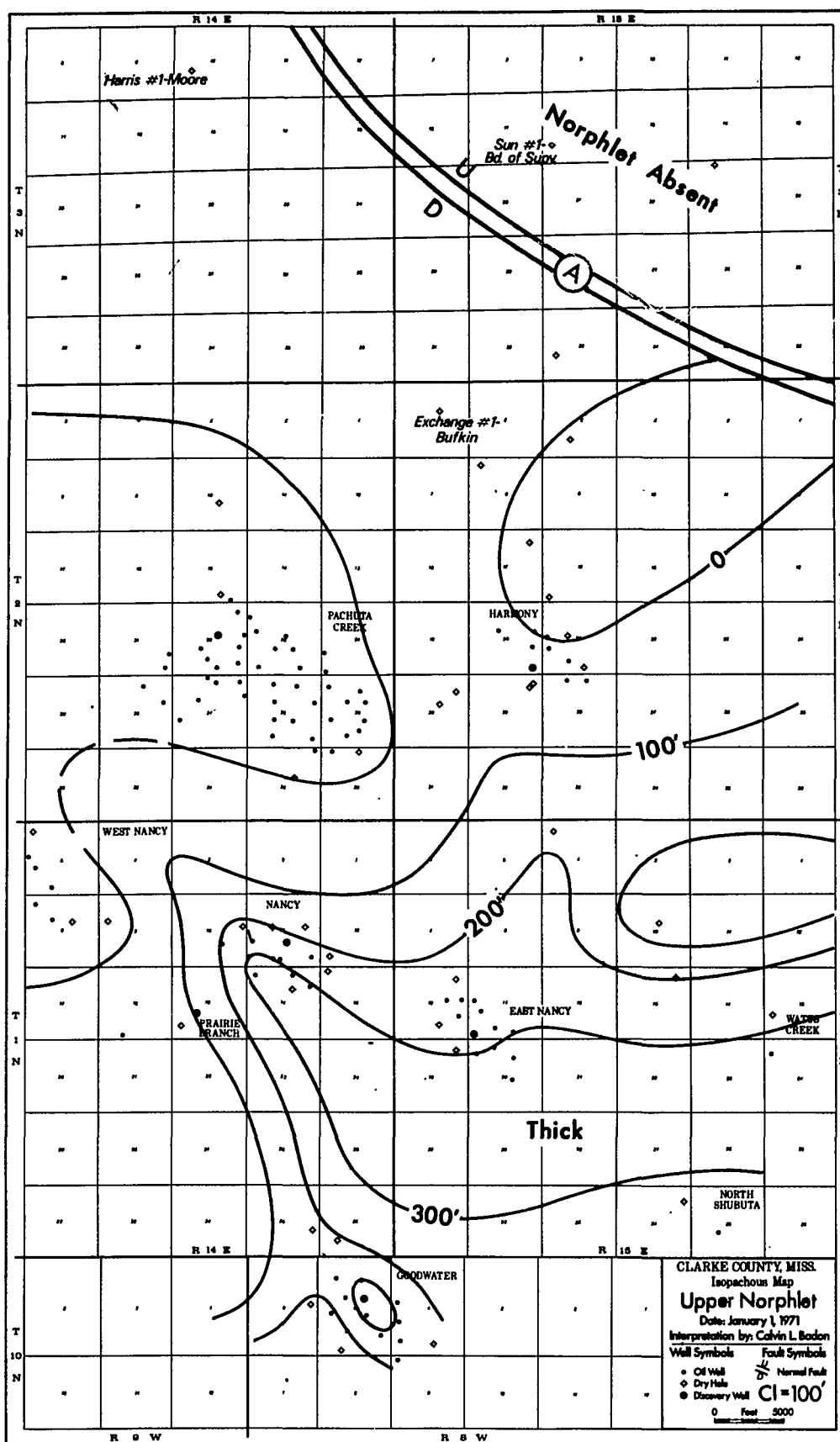


FIGURE 5. Isopach Map, Upper Member of Norphlet Formation.  
(Isopach Values in Appendix D)

south side of these structures, the upper member shows much more rapid changes in thickness than does the lower member, and variations of one hundred feet in thickness over a horizontal distance of several thousand feet are common.

## Petrology

### Quartz Sandstone Facies

At the base of the upper member, pink to red quartz sandstones overlie and are interbedded with the red siltstones of the lower member. The red sandstones vary from fine to medium-bedded (Figure 6D) with some zones of small scale cross-stratification. In other beds, the rocks appear more massive and commonly have irregular shale partings. Large white anhydrite nodules are associated frequently with these beds and are developed only where stratification is lacking (Figure 6E).

In the middle unit, the bedded grey sandstone overlies and is interbedded with the lower red sandstone unit and except for coloration are very similar in appearance. The grey sandstone beds are fine to medium-bedded with occasional small scale cross-stratification and scour features. In the upper part of the unit, the beds are distinctive in that they are laminated to fine bedded and steeply inclined at 10 to 30 degrees to the borehole (Figure 6C). It cannot be determined if these beds represent one large set of cross strata or several smaller sets since the cores are broken into smaller pieces for handling purposes. In addition, the

grey sandstone core is very friable and tends to crumble at the exposed edges during normal handling. In the case of the Exchange #1 Evans 35-1 (Plate 1) which was slabbed by the writer, particular attention was given to this problem; and it appears that from the top of the unit at 14,906 to the base of the core at 14,918, the cross stratification represents one continuous set, a minimum of 12 feet thick. In this well, stratification was made more noticeable by mud filtrate invasion along coarser grained laminae.

The third subfacies at the top of the upper member is between 20 and 30 feet thick and consists of grey homogeneous quartz sandstone. Stratification was not evident in this unit and only infrequent horizontal shale partings disrupt the homogeneous appearance. However, it is possible that some of the core pieces were broken along bedding planes and therefore went undetected. The upper contact between the Norphlet sandstone and the overlying laminated dolomite of the Smackover Formation was observed in cores from two wells in East Nancy Field. In the Getty #1 Masonite 18-8 (Figure 6B), the contact is extremely sharp and the laminated dolomite is deflected around several pebbles or pinnacles of Norphlet sandstone. In the Getty #1 Allen 20-7 (Figure 6A), the laminated dolomite abuts against a very steep and irregular upper surface of Norphlet sandstone. This core piece was found out of place in a box containing core material from several feet above the contact, but is nevertheless considered to represent the contact between these two lithologies.

FIGURE 6. Photographs: Norphlet Formation

- A. Contact between Norphlet Quartz Sandstone and Smackover Dolomite (Getty #1-Allen 20-7). Irregular surface of homogeneous anhydrite cemented protoquartzite overlain by evenly laminated dolomite.
- B. Contact between Norphlet and Smackover Formations (Getty #1 - Masonite 18-8). Overlying laminated dolomite is deflected around quartz "pebble."
- C. Bedded Grey Sandstone Subfacies. Steeply inclined (25 degrees) laminae in medium proto-quartzite.
- D. Red Sandstone Subfacies. Horizontal evenly laminated fine feldspathic greywacke.
- E. Red Sandstone Subfacies. Large white nodules of anhydrite in poorly bedded red feldspathic greywacke.



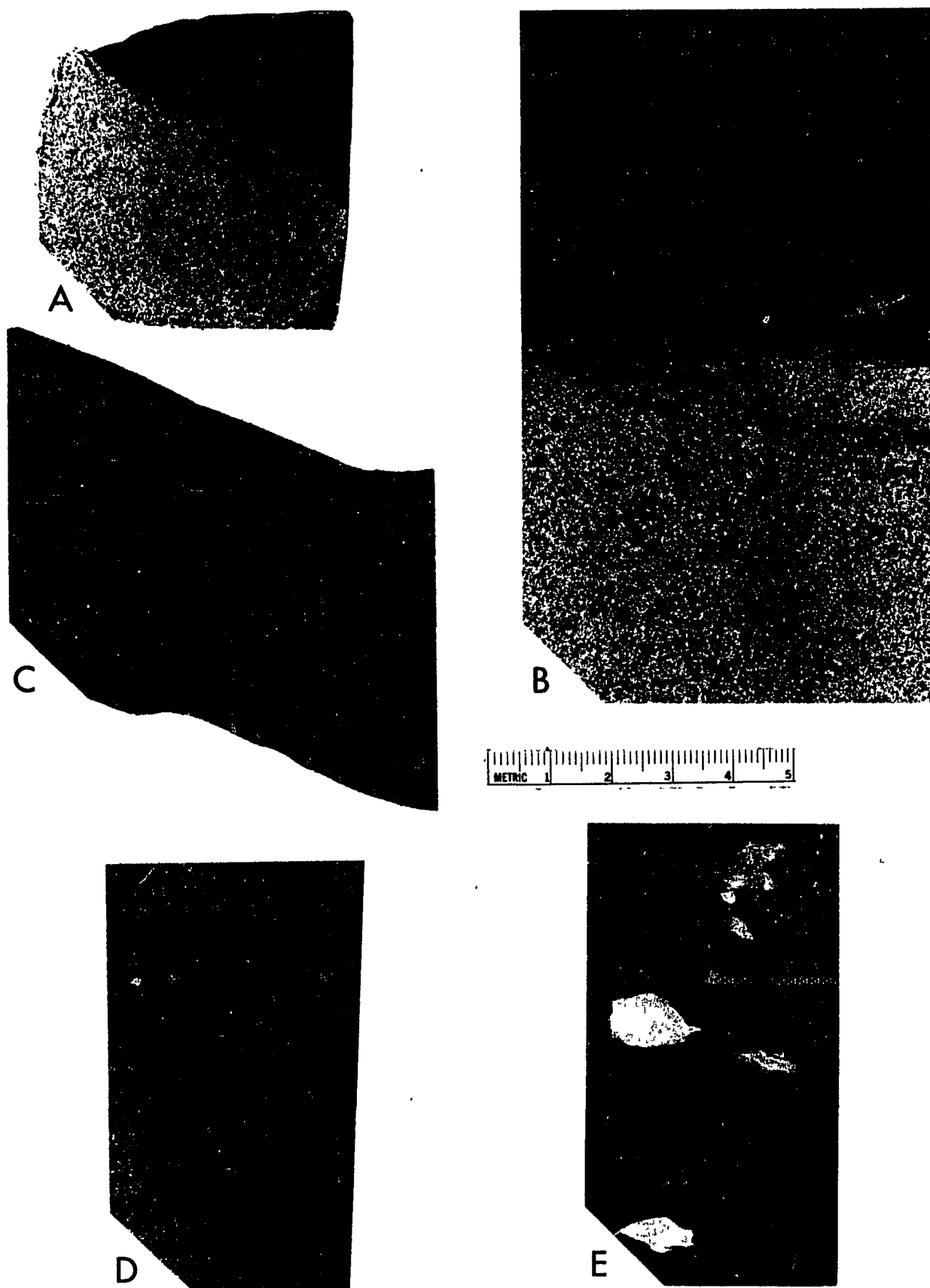


FIGURE 6

In thin-section, the upper member consists predominantly of sand-sized quartz with variable amounts of feldspar, rock fragments, and detrital matrix. These rocks are poorly cemented and where the matrix content is low, the beds are friable and have a high porosity. Although the three subfacies within the upper member were defined initially on the basis of coloration and sedimentary structures, there are also significant petrographic differences between each unit. In the petrographic description of the individual subfacies, these differences are stressed in order to aid in the analysis of depositional environments. A more detailed petrologic description of the Upper Norphlet sandstone facies is included in Appendix C.

#### Red Sandstone Subfacies

This unit consists primarily of fine sand-sized quartz grains which are angular to subangular and poorly to moderately sorted. Feldspar is much more abundant than rock fragments and commonly make up as much as 15 percent of the grain content. Detrital dolomite, in many cases indistinguishable from dolomite cement, is a prominent accessory mineral in this unit (Figure 4B). The dolomite usually has overgrowths which give the grain a more euhedral shape than the associated quartz grains. Detrital hematitic matrix fills between 30 to 50 percent of the interstitial pore space, therefore, the rocks are classified as fine feldspathic greywacke. This unit is distinguished from the overlying grey sandstone by

the presence of hematite, greater detrital matrix content, and abundant detrital dolomite.

#### Bedded Grey Sandstone Subfacies

At the base of this unit, the rocks are similar to the underlying red sandstone unit and are also classified as fine feldspathic greywackes. The principal differences are an absence of hematite and slightly less detrital matrix, between 20 to 30 percent. However, in the upper part of the bedded grey sandstone (steeply inclined strata, see Plate I), the rocks exhibit considerable difference both in composition and texture when compared to the base of the unit. Quartz plus chert make up approximately 80 percent of the grain content, and the grains are larger (medium to coarse sandsized), better rounded (subrounded to rounded), and better sorted (moderate to well sorted). Rock fragments and feldspar are present in approximately equal amounts and together seldom make up no more than 15 percent of the grain content. Detrital matrix is virtually absent in these sands and therefore the rocks are classified as either protoquartzites or subarkoses. Dolomite (Figure 4D) and anhydrite are the major cement types, but these seldom fill more than 20 to 30 percent of the pore space. Because core data were not available over the middle part of the unit (Plate I, between base of unit in the Shell #1-Johnston and upper part of unit in Exchange #1-Evans 35-1 and Getty #1-Masonite 18-8), the bedded grey sandstone subfacies cannot be treated in terms

of a continuous vertical sequence.

#### Homogeneous Grey Sandstone Subfacies

These rocks are similar to the underlying bedded sandstones except that rock fragments are usually more abundant than feldspar, and consequently the rocks are classified as medium protoquartzites (Figure 4C). Grain size is fairly uniform throughout the unit except in the uppermost part where grain size decreases to fine sand size. In this part of the unit, anhydrite cement is much more abundant and the rock is relatively well cemented (Figure 4E). At the top of the unit in the Getty #1 Allen 20-7, eighty percent of the void space was cemented by anhydrite (Figures 4E, 4F, 6A) and in the Getty #1 Masonite 18-8 (Figure 6B), anhydrite fills 30 to 40 percent of the void space.

In the area to the north of Harmony Field, the Norphlet sandstone was encountered in two wildcat wells (Exchange #1 Bufkin 6-7 and Harris #1 Moore 10-12), and appears to be fine to medium protoquartzites with a high percentage of anhydrite and dolomite cement. Dolomite fragments are associated with the quartz sandstone fragments which probably indicate that the Norphlet here consists of interbedded dolomitic quartz sandstone and arenaceous dolomites.

#### Depositional Environments of the Norphlet Formation

The black shale facies would seem to represent deposition under stagnant, low-energy conditions as evidenced by

the laminated, organic rich, fine-grained sediment. Unfortunately, the depositional relationship of this facies with the underlying Louann Formation cannot be determined because of the lack of core data from this part of the section. Black carbonaceous shales have been reported from some evaporite sequences (Peterson and Hite, 1969), and it is possible that this facies is more properly part of the underlying Louann Formation. The geometry of the shale body (Figure 3) suggests settle-out deposition in a trough-shaped depression, possibly developed during the terminal phase of Louann evaporite deposition.

The red siltstone facies is thought to represent supratidal mud-flat deposits which prograded southward as the Louann evaporite sea withdrew. Deposition probably occurred under arid conditions as indicated by the pervasive hematite (T.R. Walker, 1967) and development of early diagenetic anhydrite nodules. The nodules are considered to be formed from interstitial pore fluids concentrated by evaporation in an arid supratidal environment similar to the supratidal flats in the north-west corner of the Gulf of California (Kinsman, 1968). Evidence of desiccation in this facies is lacking, but this may be due to the absence of significant amounts of clay material. If the region were arid, soil forming processes would be retarded and the resulting product would be a clay-poor detritus derived mainly by mechanical weathering. On the evidence from one core (Plate I), the red siltstone facies coarsens upwards

and changes from predominantly hematitic mudstones to predominantly hematitic siltstones with interbedded cross-laminated fine sandstones. These upper beds are thought to be the result of alternating periods of tidal current deposition and slack-water deposition (Reineck and Wunderlich, 1968) and may represent the basal part of a transgressive sequence.

The sandstone facies of the upper member indicates a rather abrupt influx of sand-sized detritus into the area. In eastern Mississippi, the source area appears to have been from the east as the sandstone content increases in this direction (Dickinson, 1962). However, some of the micaceous rock fragments and the detrital dolomite may have been derived from land areas to the north where Carboniferous phyllitic shales and lower Paleozoic dolomites were possibly exposed at this time. The overall mineralogy of the sandstone facies is fairly uniform and suggests a single provenance for the entire sandstone sequence. Consequently, the development of the three distinct subfacies is the result of changing conditions within the basin of deposition.

The red sandstone subfacies at the base of the upper member is thought to represent a low tidal sand flat. This unit reflects a continuation of the coarsening upward trend observed in the red siltstone facies associated with an increase in sand contribution. Anhydrite nodules occur less frequently, and hematite is less pervasive than in the underlying red siltstone. The red fine-grained feldspathic greywackes appear to be in part derived from reworking of

the upper part of the red siltstone facies.

The overlying grey sandstone unit indicates an increase in current activity as bedding is well developed with scour and cross-stratification features common. The absence of hematite and the decrease in relative abundance of detrital matrix is also thought to reflect more active traction currents. If these rocks are considered to represent a continuous vertical section, then the sequence indicates a transgressive cycle from supratidal mud-flat environments grading upward into intertidal sand environments. Because these beds lack any evidence of fossils, it is not known whether normal marine conditions existed offshore or that evaporite deposition (Louann evaporites) was continuous in the basin. Similarly on the basis of one core (Plate I), it cannot be definitely established that the increase in current energy is associated with shoreline processes (intertidal) and not fluvial processes. Tyrrell, 1973, (in press) suggested that most of the upper member sandstone (referred to as "Denkman Sandstone Member" by Tyrrell) was deposited under fluvial-eolian environments. An intertidal origin is preferred for the basal part of the bedded grey sandstone subfacies because of the uniformity of grain size (fine sand-size) and conspicuous decrease in degree of oxidation of the iron-bearing grains and detrital matrix.

The stratigraphic relationship between the steeply inclined protoquartzite sandstone in the upper part of the bedded grey sandstone subfacies (Plate I) and the feldspathic

greywacke sandstone in the lower part of the subfacies cannot be determined because cores were not available in the interval between the upper and lower parts. The protoquartzite beds are laminated to fine bedded, steeply inclined (10 to 30 degrees) and consist of rounded, well-sorted sand essentially free of detrital matrix. These strata are thought to represent eolian dune sands and are very similar to inferred Norphlet eolianite sandstones described by Tyrrell, 1973. Tyrrell studied more complete core sections in Rankin County, Mississippi (80 miles west of the study area), and he concluded that most of the Norphlet sandstone strata can be characterized as large sets of steeply inclined laminations which he interpreted as eolianite sandstones. Although only partial cores of steeply inclined strata were available in the study area (Plate I, 12 feet in Exchange #1-Evans, and 10 feet in Getty #1-Masonite), these are very similar to the large sets of cross-strata described by Tyrrell and are also thought to be eolian in origin.

The homogeneous grey sandstone at the top of the Norphlet Formation may have been formed during a minor transgression of the shoreline over the coastal dune sands. This unit is 20 to 30 feet thick and consists of fine to medium protoquartzite that is characterized by an apparent lack of stratification. The homogeneity of the sandstone is possibly the result of bioturbation, although physical evidence of biological activity is lacking. As the texture and composition of the rock is similar to the



underlying cross-stratified sandstone, it seems probable that the homogeneous grey sandstone is in part derived by reworking of the underlying eolian sand bodies. In East Nancy Field, the upper surface of the homogeneous grey sandstone appears to have been at least semi-lithified prior to deposition of the overlying Smackover laminated dolomite beds (Figure 6A,6B). Early lithification by evaporite cementation could have occurred during a time of subaerial exposure and concentration of near-surface brines by evaporation. The relationship of the overlying basal Smackover carbonate beds (discussed in "Depositional Environments of the Lower Member of the Smackover Formation") seem to indicate that the Norphlet sandstone may have had some relief during the initial phase of carbonate deposition. The laminated dolomite overlying the homogeneous grey sandstone in East Nancy Field is inferred to represent deposition in a protected, shallow water area. To the south in Goodwater Field, the Norphlet sandstone is overlain by dolomitic silty micrite (probably nonlaminated) which is thought to be the offshore equivalent of the laminated dolomite beds. It is possible that during the initial phase of carbonate deposition (Smackover) linear ridges of Norphlet sandstone separated the low energy shallow water deposits (laminated dolomite) from the offshore deposits (nonlaminated micrite).

The interpretation of depositional environments discussed above is based on "spotty" core data. As the conventional cores were taken from wells several miles apart,

and each core represents only a small part of the vertical rock section, reconstruction of a composite section is hazardous. For example, it cannot be determined if the inferred intertidal sands (Shell #1-Johnston, Goodwater Field) extend as far north as East Nancy Field. Similarly, it is not known if the inferred eolian sands in East Nancy and North Shubuta Fields are continuous into Goodwater Field. Nevertheless, the conventional cores and supplementary drill cutting data indicate an overall pattern of sedimentation for the Norphlet Formation which can be summarized as follows. The withdrawal of the Louann evaporite sea was probably concomitant with an increase in detrital influx into this part of the basin. As the sea withdrew, the basal Norphlet beds (red mudstones and siltstones) prograded over the updip Louann evaporite beds. Arid conditions prevailed during this time as evidenced by the occurrence of penecontemporaneous evaporite minerals and oxidation of iron-bearing minerals in the red beds. It is possible that during this time evaporite deposition was continuous in the deeper parts of the basin. In the upper member of the Norphlet Formation, the presence of eolian dune sands may represent a continuation of arid conditions. Tyrrell (1973) reported the widespread occurrence of eolianites and suggested that desert conditions were established on the northern and western margins of the basin during deposition of the upper member sandstones. It is not known whether carbonate sedimentation (Smackover) was beginning in the

deeper parts of basin at this time or that evaporite sedimentation (Louann) was continuous.

There appears to have been several periods of minor transgressions in the overall regressive Norphlet sequence. It is thought that during deposition of the upper member sandstones, this area was situated along a low-lying desert coast such that minor fluctuations in the rate of subsidence or rate of detrital influx resulted in transgressions of the shoreline. Figure 7 is a schematic summary of the inferred facies relationships and sequential changes in depositional environments of the Norphlet Formation. At the base of the Norphlet (Figure 7A), the black shale facies is shown as part of the Louann evaporites. The overlying red siltstone facies is considered to be a supratidal regressive deposit that prograded southward as the Louann Sea withdrew from the area. In Figure 7B, the upper member red sandstone and lower part of the bedded grey sandstone are shown as transgressive deposits onlapping the underlying red siltstones. A regressive phase is shown in Figure 7C, with eolian deposits prograding southward. Figure 7D illustrates the terminal phase of Norphlet deposition during a minor transgression of the shoreline. The change from a regressive shoreline (Figure 7C) to a transgressive shoreline (Figure 7D) may have been due to a rapid decrease in the amount of detritus available. As basin subsidence continued and the amount of terrigenous detritus diminished, carbonate sedimentation began in this part of the basin.

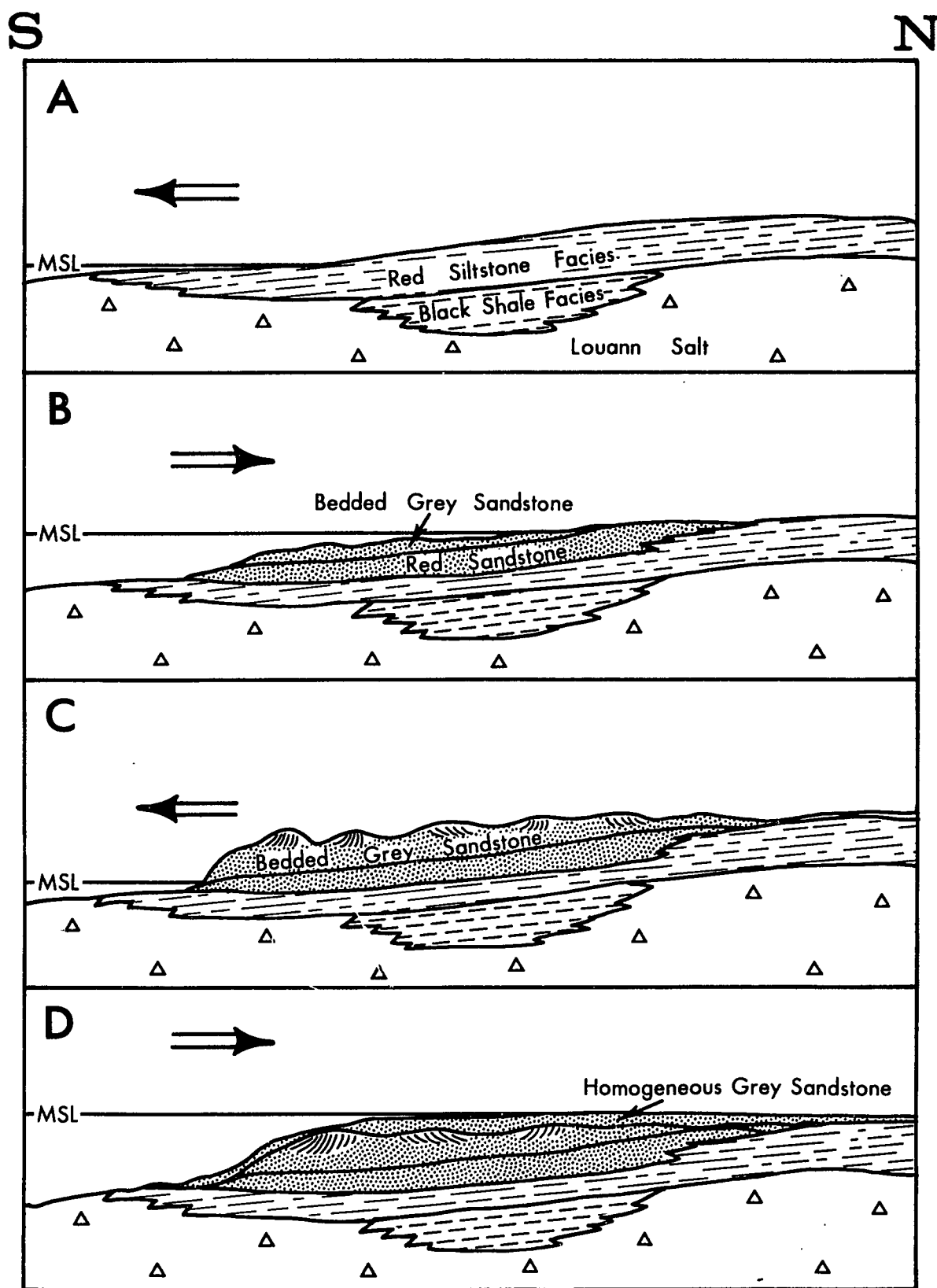


FIGURE 7. Schematic Cross-Section of Paleodepositional Environments, Norphlet Formation. Explanation in Text.

## SMACKOVER FORMATION

The Smackover Formation is present throughout the study area and ranges in thickness from 250 feet in the northeast to greater than 900 feet in the southern part of the area. The formation is subdivided into upper and lower members, each of which contains several carbonate lithofacies. The lower member is composed predominantly of micrite\* and very finely crystalline dolomite with minor amounts of spongy oncolites, intraclasts, and pellets. The upper member is in rather sharp contrast to the lower member and consists primarily of well-winnowed accretionary allochems and allochem-bearing micrites.

The petrology of the upper and lower members is based on the analysis of conventional cores and drill cuttings from the Goodwater, East Nancy, and Harmony Fields (Figure 1). For regional mapping purposes away from these areas, the electric log characteristics were usually distinct enough to determine upper and lower contacts without the aid of drill cuttings. The lower member has a typically high resistivity (as measured by the Deep-Induction curve), usually in excess of 100 ohms  $m^2m$ , whereas the resistivity of the upper member seldom exceeds 50 ohms  $m^2m$  over much of the section (Plate VI). The Isopach Maps of the upper and lower members (Figure 8 and 14) are based mainly on the DIL log "picks."

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\*The carbonate classification, carbonate grain types, and general petrographic conventions are in Appendix A.

### Lower Member

#### Stratigraphic Relationships

The lower member of the Smackover Formation generally onlaps progressively older rocks toward the North (Plate V). In the southern part of the area, the lower member rests on grey sandstone of the Upper Norphlet. In the vicinity of Pachuta Creek and Harmony Fields, it overlies Lower Norphlet red siltstones, and to the north of Fault "A" in the Sun #1 Board of Supervisors, undifferentiated Smackover carbonates overlie the Eagle Mills Formation.

The lower member can be identified usually by drill cutting samples and geophysical logs except in the region to the north of the "A" Fault where the Smackover Formation is undifferentiated. However, cores were available only in the southern area (Table 1), and most of these are in the East Nancy Field. North of Harmony Field, drill cuttings were examined from three wells: the Exchange #1 Bufkin 6-7, the Harris #1 Moore 10-12, and the Sun #1 Board of Supervisors.

As shown on Figure 8, the lower member generally thickens in a southwest direction from 300 feet in the northeast to approximately 600 feet in the southwest part of the study area. It is thin across the Harmony Field, but thickens to the south along the south side of the Pachuta Creek and Harmony Fields. In the southern part of the study area, the thickness relationships are more variable, and definite trends cannot be established. In the East Nancy Field, the

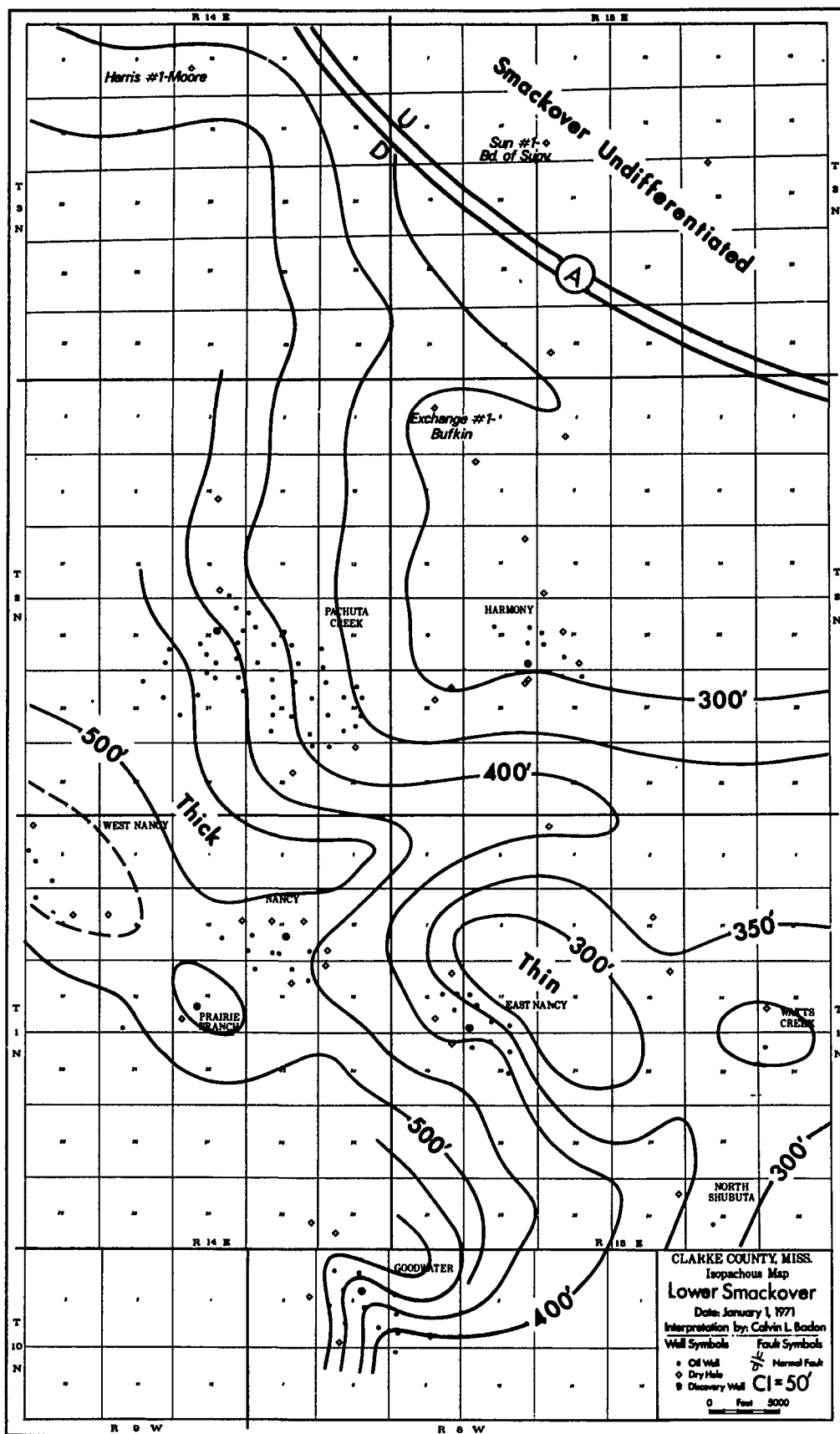


FIGURE 8. Isopach Map, Lower Member of the Smackover Formation. (Isopach Values in Appendix D)

member thickens across the structure, and a possible thin area is shown on the northeast flank. In the Goodwater Field, the lower member appears to thicken northwestward across the structure, and a similar thin area is shown to the east.

### Petrology of the Southern Area

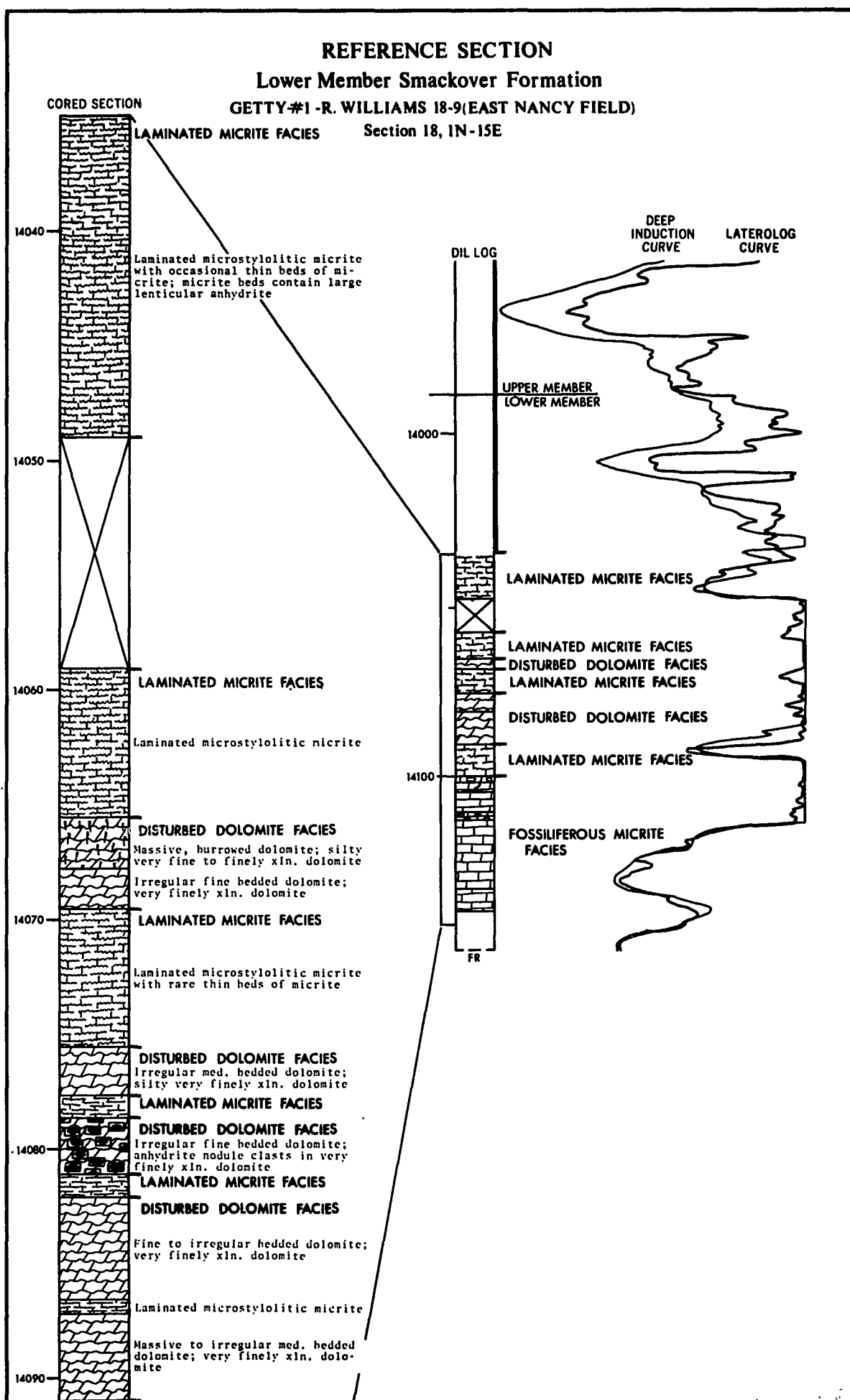
Five lithofacies were distinguished in cores from the southern area: laminated dolomite facies, mottled dolomite facies, laminated micrite facies, fossiliferous micrite facies, and oncolitic pellet facies (Plate II). The laminated dolomite facies which overlies the Norphlet Formation at the base of the sequence is the only facies that can be correlated between wells. The remaining four facies constitute the main body of the member and these appear to be discontinuous laterally between wells. Individual lithofacies are not represented by a single unit, but rather each facies is comprised of several units which are mutually interbedded with other lithofacies units. In any one core section (50 to 100 feet in length), each lithofacies may occur several times such that the entire section can be characterized as alternating lithologies. Evidently environmental conditions were fluctuating continuously with the result that individual facies repeatedly shifted laterally resulting in rapid changes in the vertical sequence in any one well. The repetition of lithofacies appears to follow a specific order; for example, units of the mottled dolomite



facies are always underlain and overlain by units of the laminated micrite facies, and are never found adjacent to units of the fossiliferous micrite facies. The relative positions of these facies in the section is critical to the interpretation of the depositional environments. The reference section for the lower member (Figure 9) illustrates the stratigraphic relationships of the three most frequently occurring facies: the mottled dolomite facies, the laminated micrite facies, and the fossiliferous micrite facies.

#### Laminated Dolomite Facies

This facies occurs only at the base of the lower member and was cored in two wells, the Getty #1 Allen 20-7 (Plate II) and the Getty #1 Masonite 18-8. In these two wells, which are approximately 4500 feet apart, the lithology was found to be identical and therefore the facies probably has lateral continuity. In addition, this unit is the only facies in the lower member that could be identified in the drill cutting samples and was recognized in samples from the East Nancy, Nancy, and Watts Creek Fields (Appendix B). The facies ranges from 30 to 50 feet in thickness and consists almost entirely of uniformly laminated dolomite (Figures 6A, 10A). In the conventional core from the Getty #1 Masonite 18-8, the core is entirely laminated dolomite from the top of the Norphlet sandstone to the top of the core interval. However, in the core from the Getty #1 Allen 20-7, the interval is entirely dolomite except for the top three feet



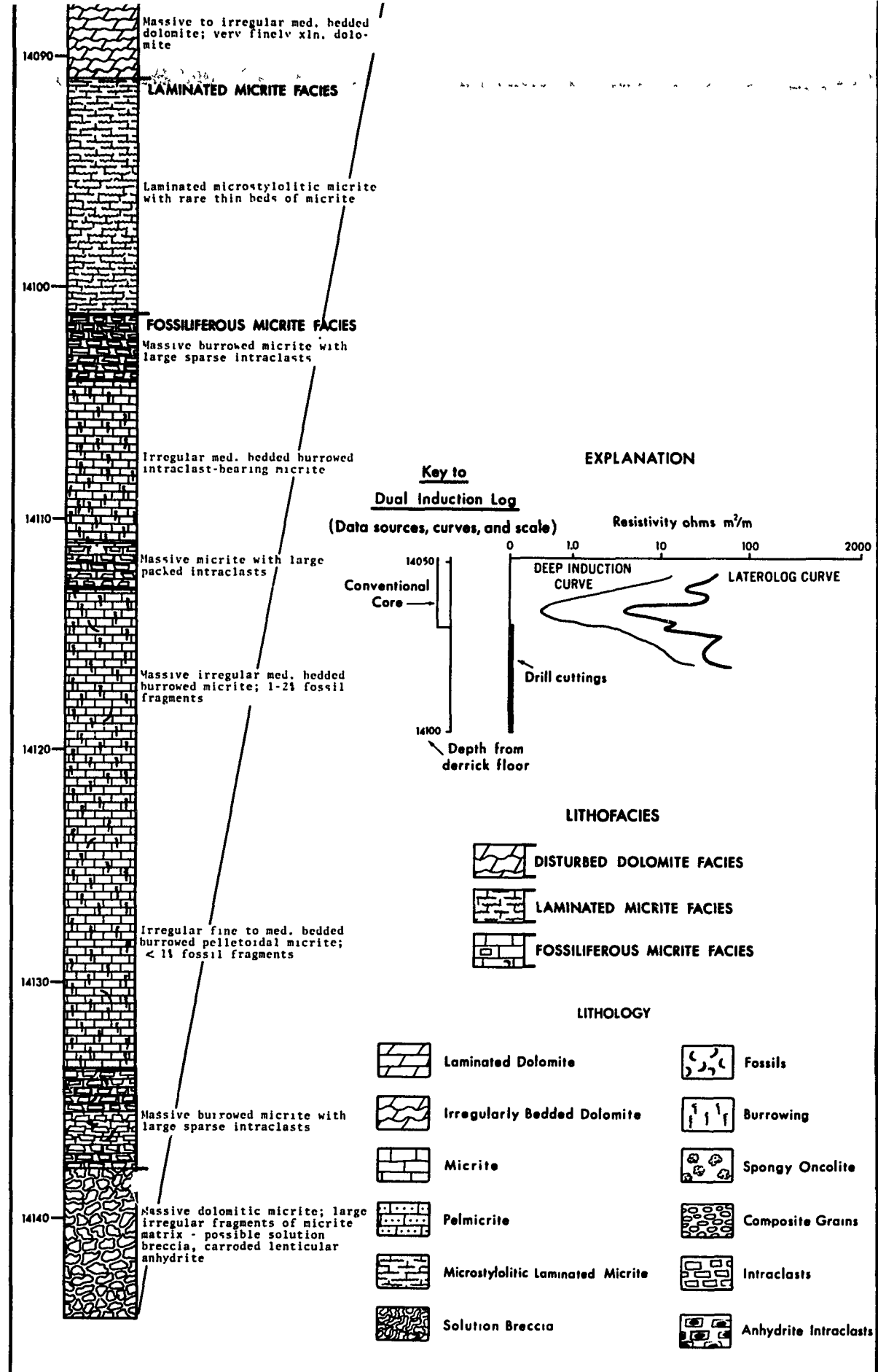


FIGURE 9. Reference Well, Lower Member of Smackover Formation

of the core which is only partially dolomitic. In this part of the core interval (Plate II), a small 5cm thick bed of nonlaminated micrite separates underlying laminated dolomite from overlying laminated micrite containing only a few scattered rhombs of dolomite. This small bed of nonlaminated micrite contains well developed fenestral or "birdseye" structures which are filled with dolomite and anhydrite.

The dolomite laminae consists primarily of small tightly packed subhedral dolomite rhombs, 0.030 to 0.060mm in size. There is no consistent size variation between dolomite crystals in alternating laminae--a condition frequently cited in the description of laminated dolomite rocks (R. D. Perkins, 1963; Carozzi and Textoris, 1967). The laminated appearance results from microcrystalline granules of pyrite and brown carbonaceous material which are concentrated in thin seams which separate laminae. Microstylolites appear to be present between laminae and are probably responsible for the concentration of the insoluble pyrite and carbonaceous material (Figure 11A). Silt-size detrital quartz is rare even at the base of the unit where laminated dolomite is in contact with the upper Norphlet sandstone. However, large mica flakes (0.100 to 0.150mm in length) were relatively abundant at the base of the unit. In thin section, the basal contact is extremely sharp, and no sand or silt-sized quartz was found in the overlying dolomite. The only exception to this is in the Goodwater Field where the basal Smackover rocks consists of silty, dolomitic micrite rather than the laminated

dolomite. Laminations were not observed in cuttings from this area, although they are normally difficult to detect in the unoriented drill cutting fragments.

The environmental interpretation of the laminated dolomite facies is deferred until the later section entitled "Depositional Environments of the Lower Member of the Smackover Formation." However, central to the question of depositional environment is whether or not the laminae of the laminated dolomite facies were formed through the binding action of algae. As algal filaments are seldom preserved in ancient dolomite rocks, the determination of algal binding of sediment is usually based upon associated sedimentary features. Where algal mats occur in the intertidal and supratidal environments, the criteria for recognition are rather well established and include stromatolite (undulating) features, desiccation features, and algal clasts (Friedman, 1969). Subtidal algal mats by contrast are less distinctive primarily because of the absence of exposure features such as subaerial desiccation and erosion surfaces. Subaqueous shrinkage (syneresis) and erosion surfaces are presumed to be much less frequent in the subtidal environment. However, Geblein (1969) studied modern Bahaman subtidal mats and reports that small scale truncations and algal clasts (flakes or chips) which are ripped up from the more cohesive subtidal mats are typical features. In the case of the laminated dolomite facies of the lower member of the Smackover Formation, there is no evidence to suggest a

FIGURE 10. Photographs: Lower Member of Smackover Formation

- A. Laminated Dolomite Facies. Parallel laminated finely crystalline dolomite.
- B. Mottled Dolomite Facies. Massive, very finely crystalline dolomite with random dark anhydrite laths (poikiloblastic). Small allochems replaced by anhydrite (white).
- C. Laminated Micrite Facies. Irregularly laminated micrite and interbedded nonlaminated micrite with probable compaction fractures filled with anhydrite.
- D. Laminated Micrite Facies. Thick unit of wavy bedded micrite. Large lenticular anhydrite crystals concentrated in lighter colored micrite beds.
- E. Fossiliferous Micrite Facies. Massive dark micrite with large sparse intraclasts. Spongy oncolite in center right.
- F. Oncolitic Pellet Facies. Massive dark pelmicrite with sparse spongy oncolites.

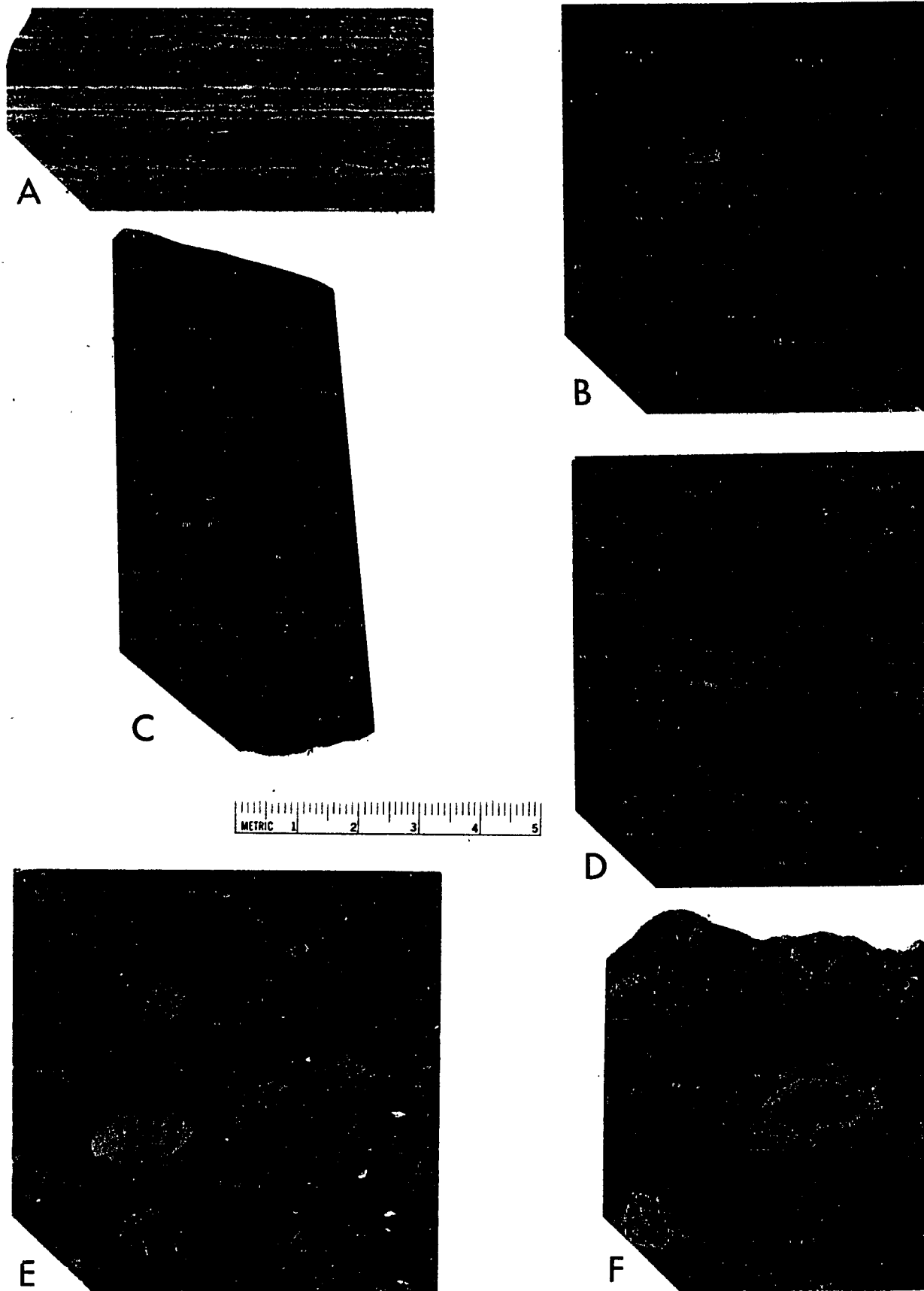


FIGURE 10

supratidal or intertidal algal origin for the laminae. Similarly, the absence of algal clasts or discernable small-scale truncation of laminae throughout the 30 to 40 feet of continuous laminated dolomite tends to preclude the possibility of a subtidal algal mat origin for the laminae. In Figure 6A, the laminations can be seen "abutting" against the irregular Norphlet surface and is not "encrusting" as would be expected if the laminae represent successive algal mats. It therefore appears likely that the parallel laminations of the laminated dolomite facies result from physical processes in which settleout deposition (gravity) of fine grained sediment occurred under restricted low energy conditions. The uniform texture of the dolomite also favors a physical origin because algal laminated dolomite commonly exhibit variation in size of the dolomite crystal between alternating laminae (R.D.Perkins, 1963; Carozzi and Textoris, 1967). It is however recognized that enlargement recrystallization of the dolomite could obliterate any evidence of an earlier dolomite textural variation.

#### Mottled Dolomite Facies

The mottled dolomite facies occurs in units which are usually less than ten feet thick and in vertical section, the units of the mottled dolomite facies are always adjacent to units of the laminated micrite facies. The beds range from poorly laminated to massive, but most commonly have a wavy or mottled appearance (Figure 10B). These beds frequently have traces of hydrocarbons, and lower Smackover production



FIGURE 11. Photographs: Lower Member of Smackover Formation

- A. Laminated Dolomite Facies. Finely crystalline subhedral dolomite with horizontal microstylolites.
- B. Mottled Dolomite Facies. Very finely crystalline dolomite with allochem replaced by large clear crystals of dolomite.
- C. Laminated Micrite Facies. Discontinuous alternating laminae of micrite (dark) and microspar (light).
- D. Mottled Dolomite Facies. Large composite grains (quiet water oolites) and preferentially dolomitized matrix.
- E. Laminated Micrite Facies. Small spindle shaped, lenticular anhydrite crystals in laminated micrite.
- F. Fossiliferous Micrite Facies. Large intraclast with lenticular anhydrite crystals, probably derived from the laminated micrite facies.

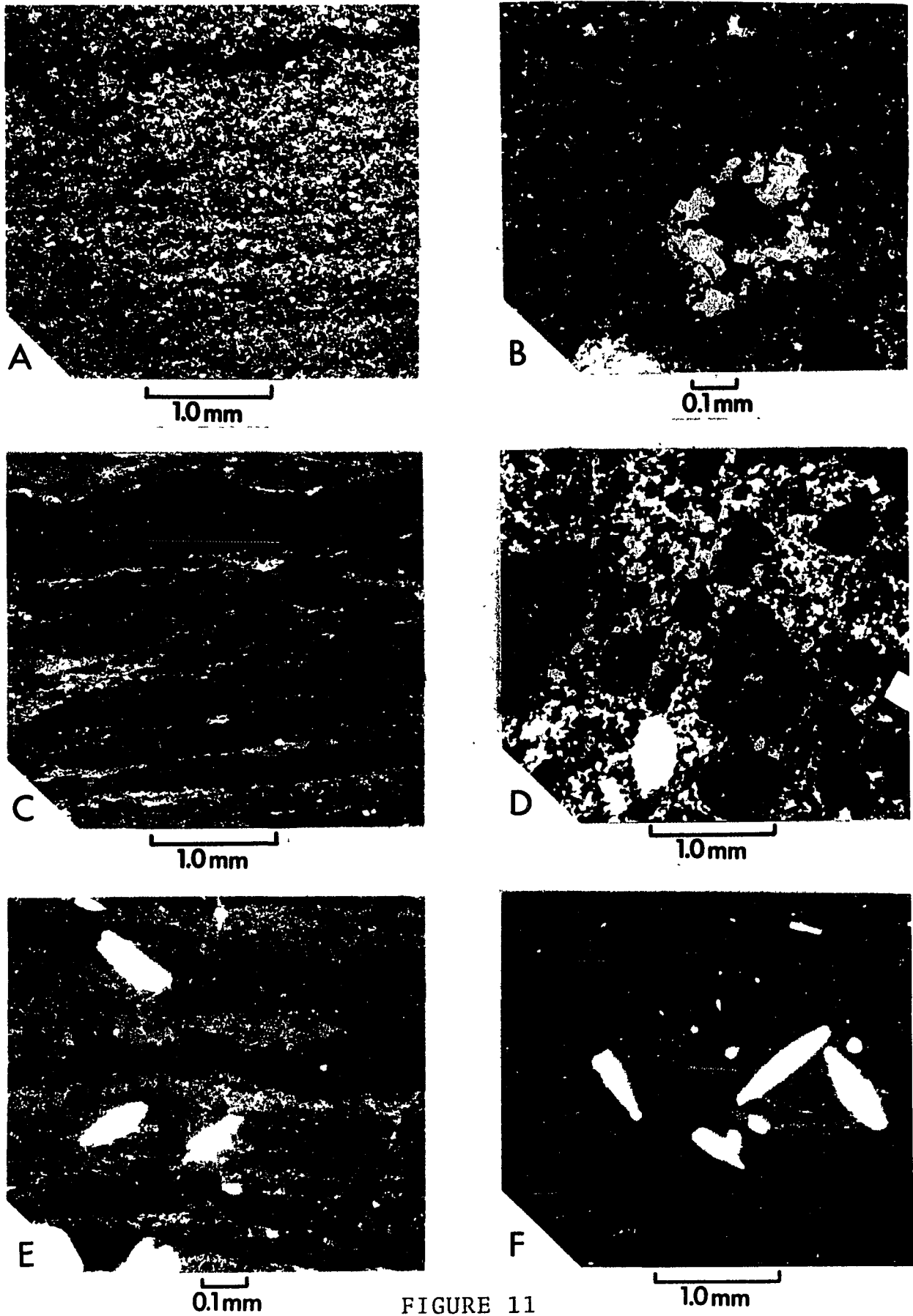


FIGURE 11

in the area is probably from this facies.

The individual dolomite crystals are smaller and more loosely packed than those in the laminated dolomite beds, resulting in a higher porosity. The crystals are usually euhedral and very uniform in size, between 0.010 and 0.015mm in diameter (very finely crystalline). Allochems are common, and where they occur "floating" in the dolomite matrix, they are almost always preferentially altered to dolomite, anhydrite, or single crystals of calcite (Figure 11B). The composition, texture, and diagenetic character of this facies is identical with beds found at the top of the Upper Smackover and in the Buckner Formation. Because of this similarity, the diagenetic character and environmental implications are discussed more fully in the later section. At the base of one of the dolomite units (in the Getty #1 Collins-Coleman well, Plate II), the allochems occur in a packed or grain-supported fabric with finely crystalline dolomite filling the interstices. In this bed, the allochems are not replaced, and consist primarily of composite grains whereas the original matrix is almost completely replaced by dolomite (Figure 11D). The allochems are similar to the "quiet water oölites" described by T. Freeman (1962), from the Laguna Madre in Texas, and the high matrix content is suggestive of deposition under quiet water conditions. In one bed (the Getty #1 R. Williams well, Figure 9), small nodules of anhydrite are scattered throughout the unit. These consist of interlocking, felty anhydrite crystals similar to those described from the Norphlet

Formation. Several of the nodules appear to be micrite-coated, and these might be clasts of early diagenetic anhydrite.

#### Laminated Micrite Facies

This facies is the most frequently occurring and was present in all five wells in which the upper and middle parts of the member were cored (Appendix B). In vertical sequence, the laminated micrite is adjacent to beds of the mottled dolomite facies and the fossiliferous micrite facies. The laminations are seldom continuous across the width of the core (3 to 4 inches) and are much more irregular (Figure 10C) than those described from the laminated dolomite facies (compare Figures 10A and 10C). The laminated sequence is frequently interrupted by small beds of nonlaminated micrite (Figure 10D) which occasionally contain large crystals of lenticular anhydrite.

Lenticular anhydrite is restricted essentially to this facies (see "Description and Origin of Anhydrite," Appendix A4). In the laminated micrite facies, the anhydrite crystals occur as randomly oriented single crystals which exhibit a characteristic lenticular or discoid shape. Two crystal sizes appear to be typical: in the nonlaminated micrite beds (Figure 10D), they are usually 1 to 2mm in length, whereas in the laminated micrite beds the crystals rarely exceed 0.5mm in length (Figure 11C). These lenticular anhydrite crystals are considered to be pseudomorphs after

primary, early diagenetic gypsum. Lenticular gypsum forming in present day intertidal and supratidal environments has been reported by several authors from both carbonate coastlines (Kinsman, 1966, 1969; Davies, 1970) and noncarbonate mud flats (Eardley and Strickland, 1952; Masson, 1955). In ancient rocks, lenticular or discoid anhydrite has been recorded as pseudomorphs after primary gypsum by Kerr and Thompson (1963), and West (1964).

#### Fossiliferous Micrite Facies

The fossiliferous micrite facies is present in most study wells (Appendix B), but is best developed in the Getty #1 R. Williams, Figure 9. Although this facies is described as fossiliferous, fossils seldom make up more than one or two percent by volume of the rocks. It is, however, a distinctive characteristic of the facies because fossils were never found in the laminated dolomite facies, mottled dolomite facies, or the laminated micrite facies, and occur only rarely in the oncolitic pellet facies. A rather wide variety of lithologies are included in this facies: bedded micrites, massive (commonly burrowed) intraclastic bearing micrites (Figure 10E) and burrowed micrites. In vertical section, the bedded micrites and intraclast-bearing micrites invariably occur adjacent to the laminated micrite facies.

The dominant constituent of this facies is micrite which occasionally has a pelletoidal or "grumeleuse" appearance, especially in the reference well. The only allochems observed

were fossils which are ubiquitous, although always in minor amounts, and intraclasts which are found in local concentrations. The most frequent bioclast types are echinoid spines and plates, and fragments of brachiopods and gastropods. The intraclasts are composed of micrite and microspar and are highly variable in size, ranging from 0.100mm to several cms. in diameter. Many of the intraclasts have a crinkly laminated appearance, and are probably derived from the laminated micrite facies. Lenticular anhydrite is rarely found in this facies and where present is usually associated with intraclasts seemingly derived from the laminated micrite facies (Figure 11F). This is taken as evidence of the early diagenetic occurrence of lenticular gypsum in the laminated micrite facies.

#### Oncolitic Pellet Facies

The Oncolitic Pellet Facies is present only in the Getty #1 Allen 20-3 well (Plate II) where it occurs between intraclast bearing micrite units. The typical appearance of this facies is massive and dark colored with lighter colored spongy oncolites prominently displayed against the darker background (Figure 10F). The oncolites are very large and occasionally measure several centimeters in diameter and are exclusively of the spongy or loosely organized variety (see discussion on oncolites in Appendix A3).

The major allochem type is spherical, well-defined pellets, which range in size from 0.040 to 0.070mm in diameter.

Commonly, the pellets merge and appear to be part of a continuous micrite network. In appearance, they are very similar to the "granuloid" texture described by Wolf (1965, p.20) which he interpreted as autochthonous "granuloid" algal material. Where spongy oncolites are developed, layers of pellets are enveloped between micrite laminae. However, the oncolites are best seen in polished section because in thin section it is sometimes difficult to distinguish between the oncolitic texture and the "granuloid" texture of the ground mass. Fossils are rare in this facies, and only a few echi-noid fragments were noted.

#### Petrology of the Northern Area

In order to determine the lithologic variation of the lower member in the northern part of the study area, drill cuttings were examined from the Exchange #1 Bufkin 6-7 (WC/Sec. 6, 2N-15E), the Harris #1 Moore 10-12 (WC/Sec. 10, 3N-14E), and the Sun #1 Board of Supervisors (WC/Sec. 16, 3N-15E). The location of these wells can be seen on Figure 8. Because only drill cuttings were available in this area, individual lithofacies such as those described in the southern area cannot be distinguished, and only a general lithologic comparison can be made between the two areas. Drill cuttings were not available in Harmony Field, and therefore, a gap is shown between the southern and northern areas on the regional cross section (Plate VI).

Exchange #1 Bufkin 6-7

This well is situated on the extreme northwest flank of the Harmony Field and contains approximately 290 feet of dark brown micritic rocks which are assigned to the lower member. Crinkly laminated micrite was the most frequently occurring type of fragment, but some intraclast bearing micrite fragments were also noted. At the base of the sequence, 40 to 50 feet of laminated dolomite is present which is considered to be equivalent to the laminated dolomite facies described from the southern area. Because of the gross similarity between the cuttings in the Exchange well and those in the southern area, the lower member is probably continuous across the Harmony structure.

Harris #1 Moore 10-12

This well is the most northerly in the study area and is considered to be downthrown to the large "A" fault. The interval from 11840 to 12180 feet (measured depth) is included in the lower member because of the brown carbonaceous and micritic nature of the drill cuttings. However, the appearance of these cuttings in thin section is quite different from the cuttings observed in the southern area. Unlike the intraclast bearing micrite described in the East Nancy Field, both the intraclasts and matrix have been completely recrystallized to microspar so that only ghosts of the intraclasts are seen. In addition, the intraclasts appear to be smaller than the intraclasts found in the southern area, and are



better rounded and more uniform in size (0.100 to 0.300mm). Larger intraclasts, such as those shown in Figure 10E, would not be identified as intraclasts because of the limiting size of the drill cutting fragments.

#### Sun #1 Board of Supervisors

This well lies approximately six miles southwest of the Harris #1 Moore and is thought to be upthrown to the "A" fault. Approximately 250 feet of dolomite is present between 10690 and 10940 feet (measured depth) which is considered to be equivalent to the Smackover Formation. Although 100 feet of this interval was cored between 10710 and 10800 feet, the core was not available and the description of the rocks is based solely on drill cuttings over the interval 10800 to 10940 feet. Data are insufficient to determine if this dolomite sequence is equivalent to the entire Smackover or only part of the formation. The rocks consist primarily of finely crystalline dolomite with minor amounts of microspar. Some of the microspar fragments contain pellets or small intraclasts similar to those described in the Harris #1 Moore 10-12. At the base of the Smackover sequence, several dolomite fragments were noted which contain a high percentage of material which is thought to be argillaceous.

#### Depositional Environments of the Lower Member,

##### Smackover Formation

Deposition of the laminated dolomite facies at the base

of the lower member probably occurred under restricted, quiet water conditions. Preservation of the parallel laminations and the complete lack of faunal evidence suggests very restricted conditions. The dolomitized parallel laminations are thought to be the result of physical processes rather than algal binding. Apparently, the water depth was very shallow as evidenced by a single occurrence of "birds-eye" structure which is most frequently associated with intertidal and supratidal environments (Shinn, 1968). However, more direct evidence of subaerial exposure such as mud cracks and rip-up clasts are lacking. The paucity of silt-size quartz and the absence of sand-size quartz reflect an abrupt cessation of detrital influx into this part of the basin. In the East Nancy Field area, the laminated sediment is envisioned as being deposited in a shallow water protected area. To the south, in Goodwater Field, the laminated dolomite facies is absent and dolomitic micrite (probably nonlaminated) overlies the Norphlet beds. The nonlaminated micrite is thought to represent the offshore equivalent of the laminated dolomite. Whether or not these facies were separated by a topographic barrier lying between the two fields cannot be determined because of the absence of wells in this area.

The mottled dolomite beds in the main body of the lower member are very similar in composition and fabric to the dolomite beds found in the upper part of the Smackover Formation and the lower member of the Buckner Formation

(which are thought to have been deposited in lagoonal and supratidal environments, respectively). The size and appearance of the very finely crystalline dolomite and the nature of the diagenetic alteration of the allochems are identical in every respect. Unlike the subhedral coarser grained (finely crystalline) dolomite at the base of the lower member, the very finely crystalline dolomite in the mottled dolomite beds is considered to be early diagenetic. The evidence for early diagenetic dolomite is more equivocal than in the upper member of the Smackover Formation and the lower member of the Buckner Formation where fabric selective dolomitization, dissolution of allochems, and extensive development of anhydrite nodules are more clearly defined. Nevertheless, the occurrence of lagoonal-type deposits (quiet-water oölites) and nodular anhydrite clasts probably indicate a close proximity to supratidal environments.

The laminated micrite beds which occur most frequently throughout the sequence are thought to have been deposited under restricted intertidal to subtidal conditions. The laminations are probably the result of sediment binding by blue-green algae, although definite physical evidence such as complex growth forms (stromatolites) are lacking. However, on the micro-scale, the irregularly stacked, crinkly laminae are suggestive of sediment binding by algae. Gebelein (1969) reported the presence of subtidal algal mats from Bermuda which lack desiccation features or crinkling on a macro-scale, although microtruncations are fairly common.

Perhaps the best evidence for an algal origin lies in the associated facies which contain clasts of crinkly laminated sediment. Algal bound fine grained sediments would be sufficiently cohesive (A. C. Neumann, et al., 1970) to be ripped up and moved into adjacent areas. When the stratigraphic position is considered, it is evident that this facies is bounded on one side by shallower water conditions (mottled dolomite facies) and on the other side by deeper water conditions (fossiliferous micrite facies). However, the occurrence of early diagenetic lenticular anhydrite crystals, perhaps pseudomorphic after gypsum, tends to support an upper intertidal to supratidal origin. Kinsman (1969) reported lensoid gypsum from intertidal deposits in the Trucial Coast area, and Davies (1970) reported lensoid gypsum from supratidal deposits in the Shark Bay area of Western Australia. A subtidal origin is nevertheless preferred because of the lack of evidence for subaerial exposure. As the lenticular anhydrite crystals are both larger and more abundant in the interbedded micrite units, these beds may well represent intermittent periods of more shallow water (intertidal).

The fossiliferous micrite facies represents more normal marine conditions as evidenced by the sparse fossils and burrowed micrite. However, the facies does not appear to be continuous between wells, and it is doubtful that a large body of normal marine water was present in this area during deposition of the Lower Smackover. Fossils are few in number,

and do not exhibit the variety of forms found in the upper member of the Smackover Formation. The fossiliferous micrite facies is therefore thought to be deposited in local partially restricted seaways, possibly connected to more open marine waters by tidal inlets. These seaways are envisioned as being flanked by the subtidal algal laminated sediment. During intermittent high energy events such as storms, the semiconsolidated (algal-bound) laminated sediment would be ripped up and moved into the areas of deeper waters. Intraclast-bearing micrites which occur in vertical sequence between the burrowed micrite and the laminated micrite possibly represent sediments deposited in this manner on subtidal slopes adjacent to the laminated micrite facies.

The environment of deposition of the oncolitic pellet facies was probably similar to that of the fossiliferous micrite facies as these two facies are closely associated in vertical sequence and both are adjacent to the laminated micrite facies. However, the environment appears to have been more restricted, both with respect to the fossil assemblage and energy conditions. Gebelein (1969) studied the distribution and morphology of algal biscuits in Bermuda and observed that they are particularly sensitive to water depth and current velocity. If the Bermuda algal biscuits can be used as an analog for the irregular spongy oncolites, then the water depth was less than ten feet and the surface current velocity was very low. In slightly deeper water or where current energy was higher, the fossiliferous micrite

was favored.

The interpretation of the depositional environments of the four lithofacies in the main body of the lower member is shown in the schematic summary diagram (Figure 12). The lateral distribution of the facies is inferred from their association in the vertical sequence. These facies do not represent a continuous progradation or transgression, rather the facies relationships indicate fairly continuous deposition near mean sea level with carbonate sediment production essentially maintaining equilibrium with basin subsidence. Under these conditions, minor changes in this equilibrium situation would cause lateral shifting of the facies. It is probable that the entire lower member carbonate section (300 to 500 feet thick) in this area was deposited under very restricted, shallow water conditions. The general lack of fossils or evidence of bioturbation (except for rare occurrences in the fossiliferous micrite facies) suggests that no permanent connection with open marine waters existed during deposition of the lower member.

### Upper Member

#### Stratigraphic Relations

The upper member of the Smackover Formation consists of several carbonate lithofacies which are thicker and more widespread than those of the lower member. The lower boundary of the member is drawn at the contact between pelletoidal micrite (upper member) and micrite (lower member) as determined

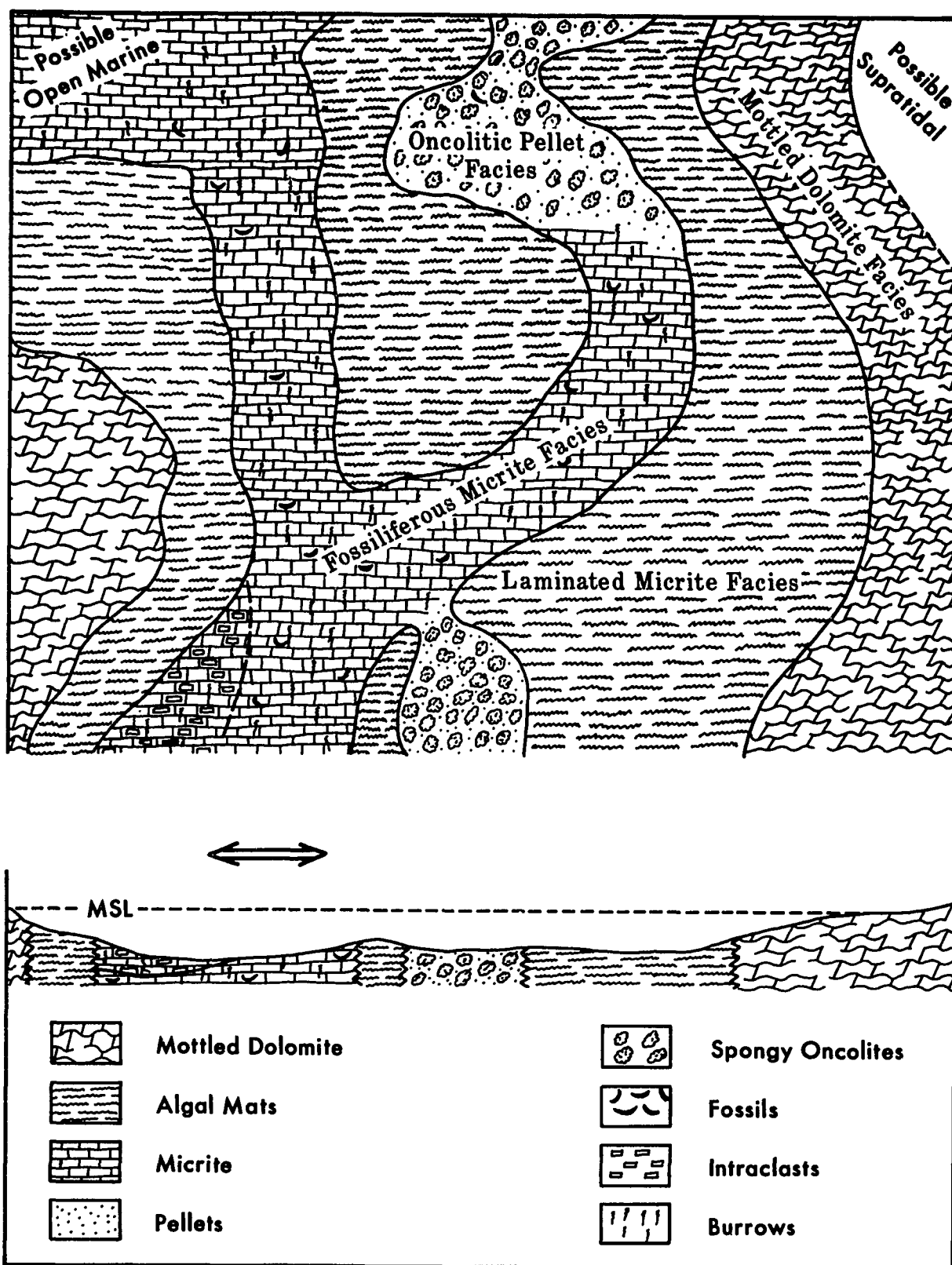


FIGURE 12. Schematic Summary of Paleodepositional Environments, Lower Member of the Smackover Formation

by examination of drill cuttings. Because these two lithofacies are interbedded, the boundary is often arbitrary, and the base of the upper member is picked where the sample lithology changes downward to predominantly micrite. For mapping purposes, the contact was picked by DIL log correlation where drill cuttings were not examined.

The six lithofacies which constitute the upper member are: pelletoidal micrite facies, superficial oömicrite facies, pelmicrite facies, oölite facies, oncolitic superficial oölite facies, and oölite-quartz dolomite facies. The stratigraphic relationships of these facies are shown on the cross section (Plate III) which includes both the upper member of the Smackover Formation and the lowermost part of the Buckner Formation. This cross section is considered to be oriented roughly parallel to the depositional dip direction and includes wells from the Goodwater, East Nancy, and Harmony Fields, and two wildcat wells in the northern or up-dip area. The contact between the Smackover and Buckner Formations is used as the reference datum for the cross section for all of the wells except the most northerly well, the Harris #1 Moore 10-12. This well is lowered on the cross section relative to the other wells in order to illustrate the inferred facies relationships between the Buckner and Smackover Formations. For convenience purposes, the facies relations are illustrated also on the schematic cross section (Figure 13) which was simplified from the stratigraphic cross section (Plate III).



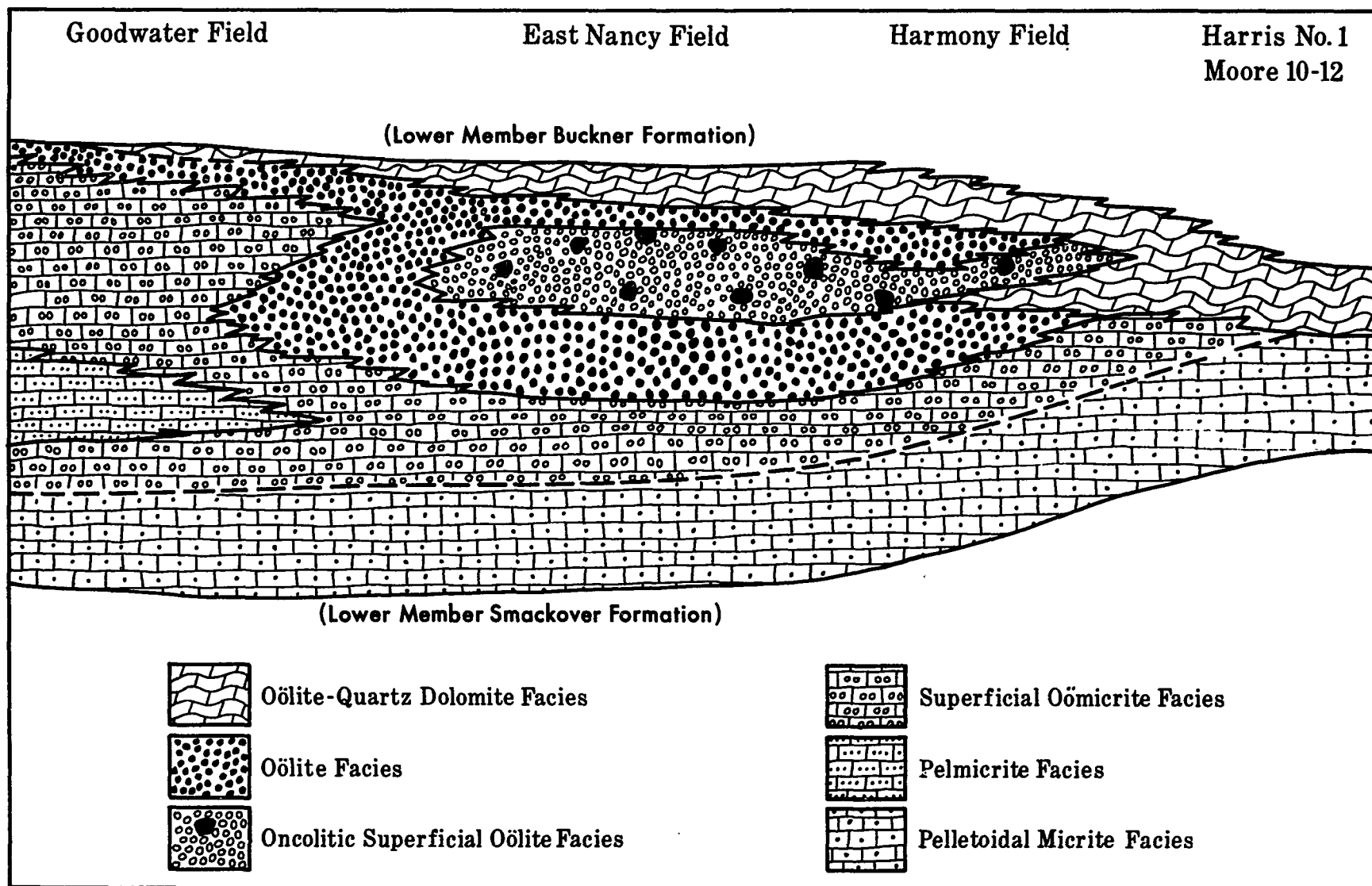
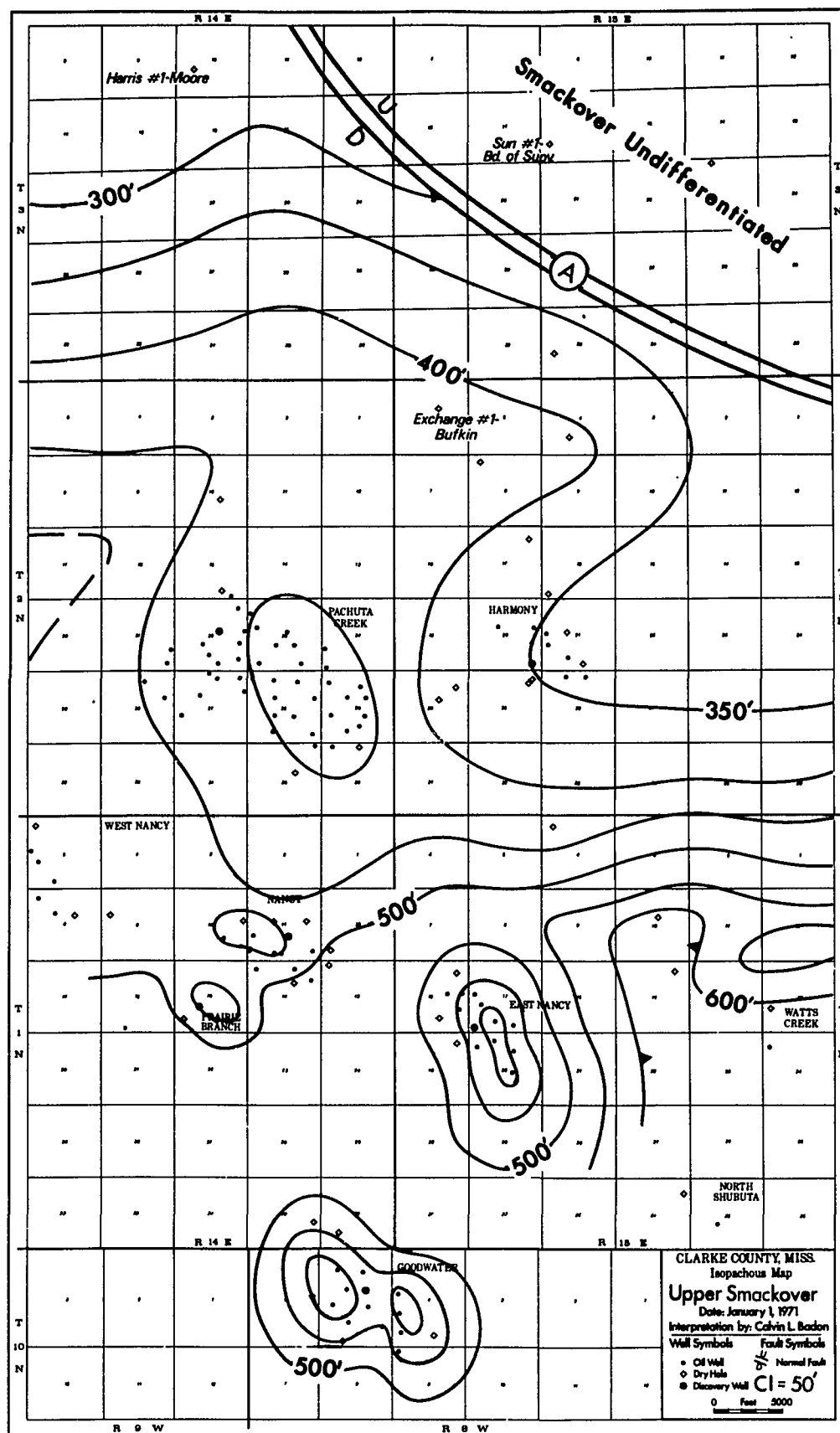


FIGURE 13. Schematic Cross-Section Showing Relationships of the Six Upper Smackover Lithofacies From Goodwater Field (South to the Most Northerly Well, Harris #1 Moore 10-12 (Diagram taken from Plate III)

The upper member of the Smackover Formation is the most extensively cored part of the Jurassic section in the eastern Gulf region. However, the conventional cores are concentrated in the uppermost part of the member in the more porous and permeable oölite and oncolitic superficial oolite facies. In the lower part of the member, only drill cuttings were available, and consequently much less is known about the facies in this part of the section. For this reason, the three upper facies (oölite, oncolitic superficial oölite, and oölite-quartz dolomite facies) are discussed in greater detail and the interpretation of depositional environments is more definitive. In the case of the lower three facies (pelletoidal micrite, pelmicrite, and superficial oömicrite) which were identified primarily on the basis of rock "chips" recovered during the drilling operation, the facies are more poorly defined, and their inferred depositional environments less certain.

The upper member ranges in thickness from 300 feet in the northern part of the study area to 600 feet in the southern part (Isopach Map, Figure 14). Unlike the lower member, deposition of the upper member was clearly affected by salt movement which is best illustrated by thinning over the East Nancy structure. Possible isopachous closure is also suggested in the Goodwater and Nancy Fields, but the data is insufficient to establish definite thickening on the flanks of these structures. In the area of Harmony and Pachuta Creek Fields, the Isopach map is similar to that



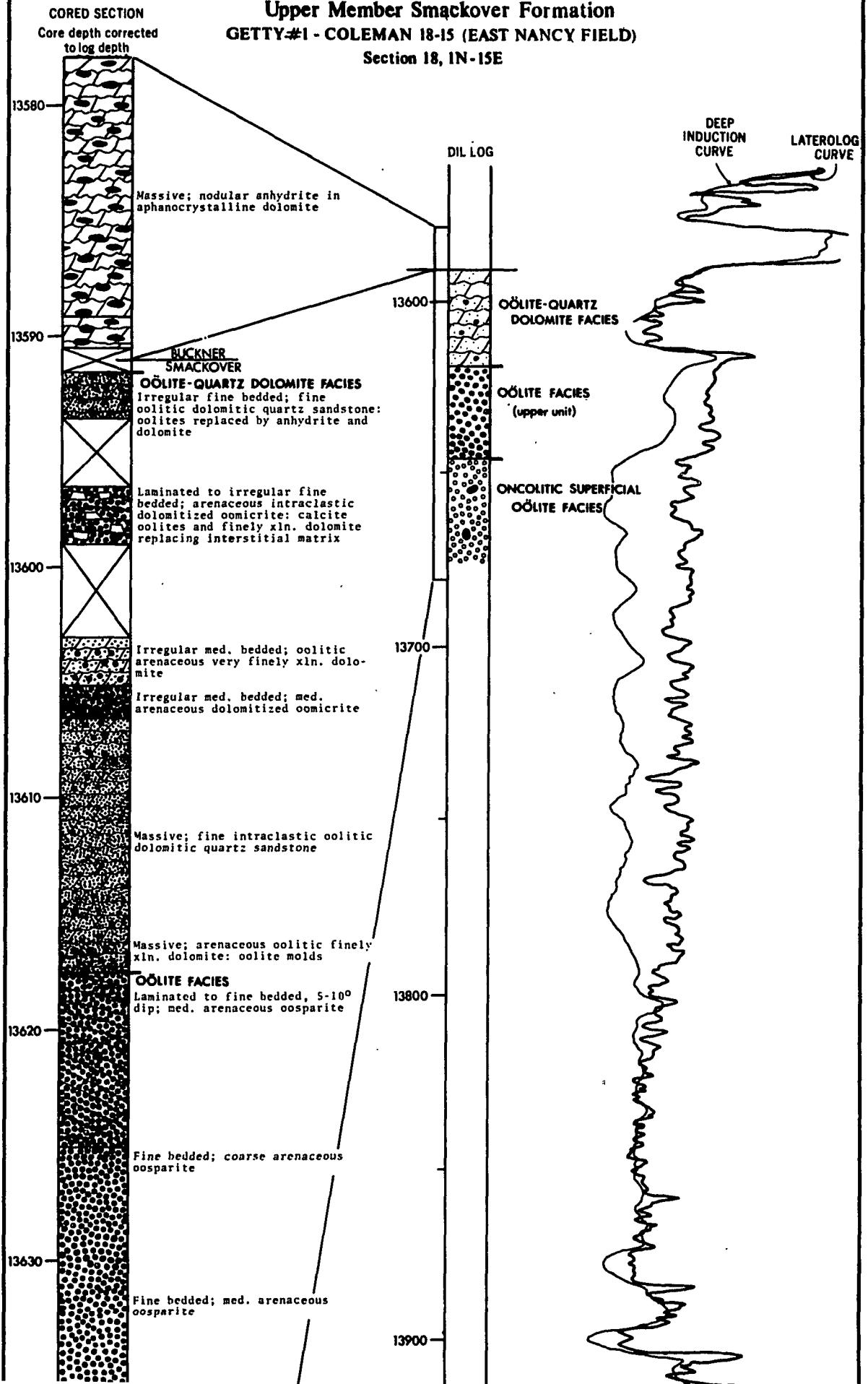
shown for the lower horizons and probably reflects a broad structural salient developed independently of salt movement.

### Petrology

The carbonate facies which make up the upper member are defined primarily on the basis of allochem type and matrix, as these criteria are thought to reflect more clearly the environmental conditions at the time of deposition (R. L. Folk, 1959). Table III, p.100 is a summary chart of the petrology of the upper member which depicts the relative abundance of allochem types (including detrital quartz), matrix and cement types (micrite/calcspar/dolospar), and fossil content for each of the six lithofacies. The three upper lithofacies, oölite facies, oncolitic superficial oölite facies, and the oölite-quartz dolomite facies, are treated in more detail as most of the conventional cores are from this part of the section. The Getty #1 Coleman 18-15 East Nancy Field was selected as the reference well (Figure 15) and is considered to be representative of the upper member. Because of the importance of the oölite facies and the oncolitic superficial oölite facies to production of oil and gas, a special section on cementation is included in this study. These marine beds are thought to have been buried to their present deep subsurface position without subsequent exposure to vadose conditions; therefore, there is a unique opportunity to study cementation under continual burial conditions.

# REFERENCE SECTION

## Upper Member Smackover Formation GETTY-#1 - COLEMAN 18-15 (EAST NANCY FIELD) Section 18, 1N-15E



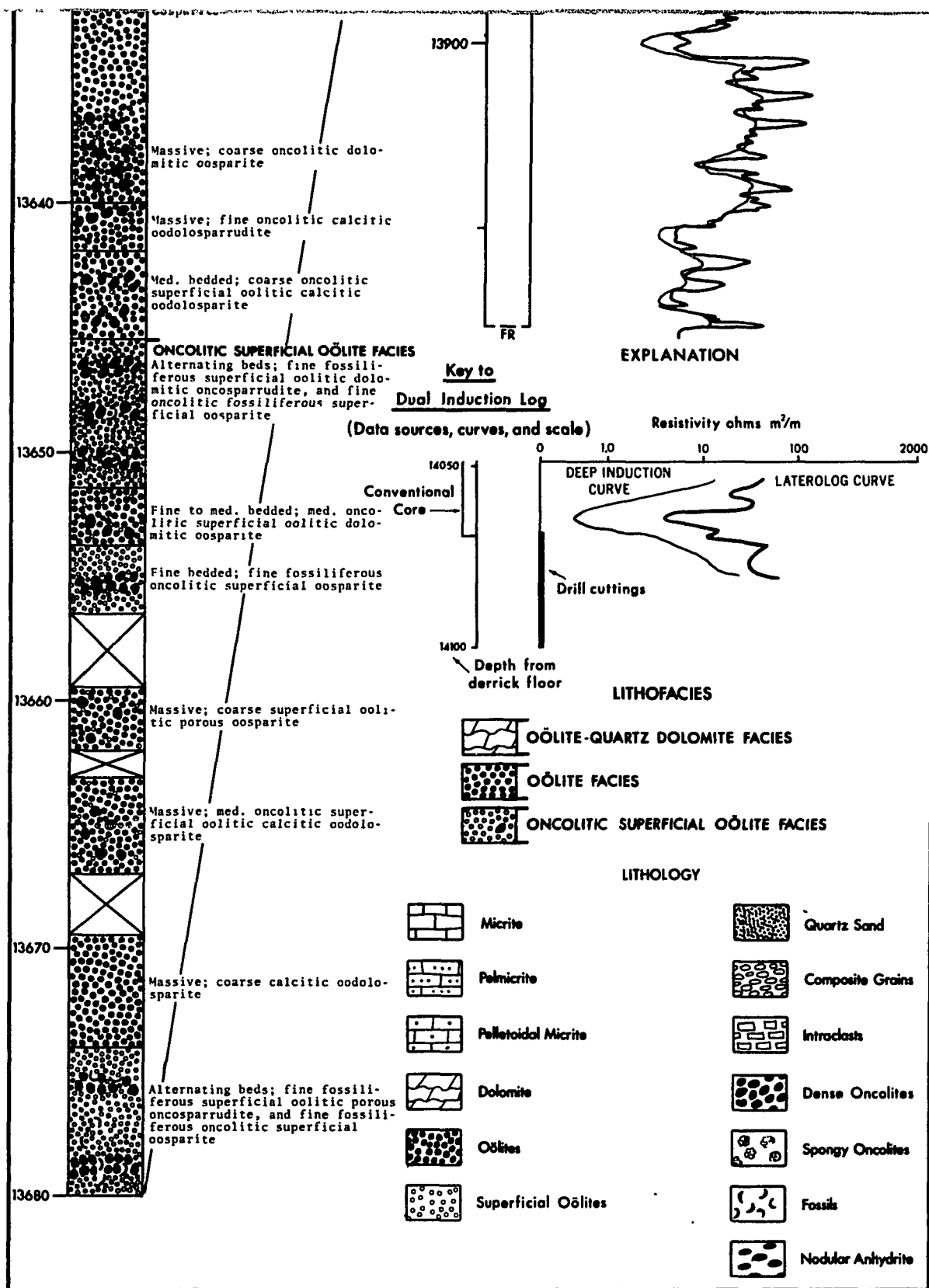


FIGURE 15. Reference Well, Upper Member of Smackover Formation

### Pelletoidal Micrite Facies

The Pelletoidal micrite facies occurs at the base of the upper member and is defined solely on the basis of drill cutting samples. Interbedded units of dolomitic pelletoidal micrite which are shown on the stratigraphic cross section (Plate III) by dotted lines are characteristic of this facies. The facies appears to be developed throughout the area although cuttings were not available for examination in the vicinity of Harmony Field. In the most northerly well, the Harris #1 - Moore 10-12 (Plate III), the interval between 11720 and 11840 feet is included in the pelletoidal micrite facies. However, in this well the rocks are more extensively recrystallized to microspar so that the pelletoidal character is less apparent than in the wells to the south. Also an anomalous lithology (micrite) was noted between 11680 and 11720 feet. This unit was not observed in any other well in the upper member, and its stratigraphic relations with other facies is unknown at this time.

In thin section, the drill cutting samples display rounded or ellipsoidal aggregates of "grains of matrix" material (Figure 16A). This feature is similar to the "clotted" texture described by Cayeux, 1970, p. 253 and the pelleted or pelletoid texture of Bissell and Chilingar, 1967, p. 163. The term pelletoidal micrite is used in this study to distinguish between underlying micrite (lower member of Smackover Formation) and overlying pelmicrite in which pellets with distinct boundaries are embedded in a micrite

FIGURE 16. Photographs: Pelletoidal Micrite Facies and Superficial Oömicrite Facies.

- A. Pelletoidal Micrite Facies. Small indistinct pelletlike masses of micrite (p) and secondary dolomite rhombs (d). The dolomite here is not fabric selective, and replaces the pellet-like objects and micrite matrix alike. Thin section of drill cutting fragment.
- B. Pelletoidal Micrite Facies. Dolomite (d) almost completely replacing original pelletoidal micrite, with only relict patches of microspar (m) remaining. Thin section of drill cutting fragment.
- C. Superficial Oömicrite Facies. Small oölitically coated pellets and smaller size pellets. Interstitial material is primarily micrite with lesser amounts of calcspar cement.
- D. Superficial Oömicrite Facies. Edge of spongy oncolite with center near lower left corner. Small pellets (p) with interstitial open spaces are enclosed between oncolitic laminae (l).



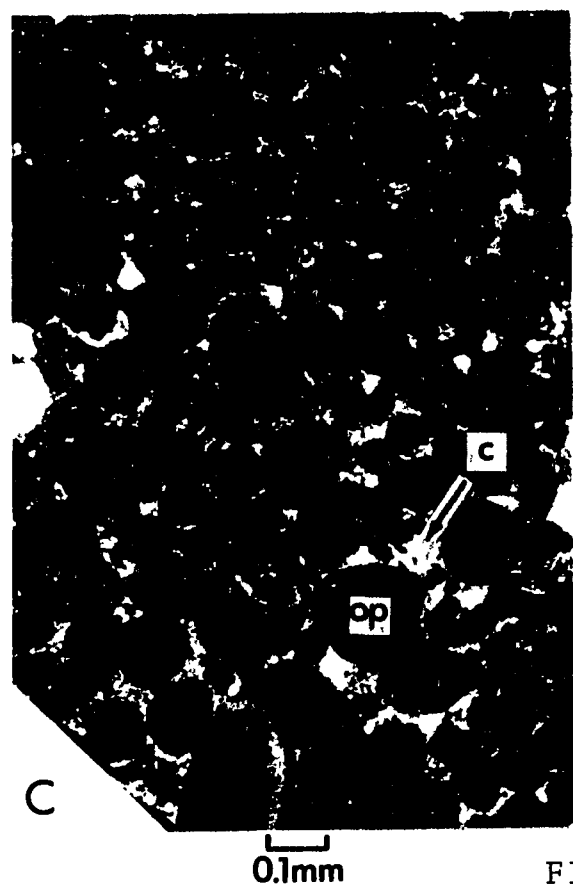
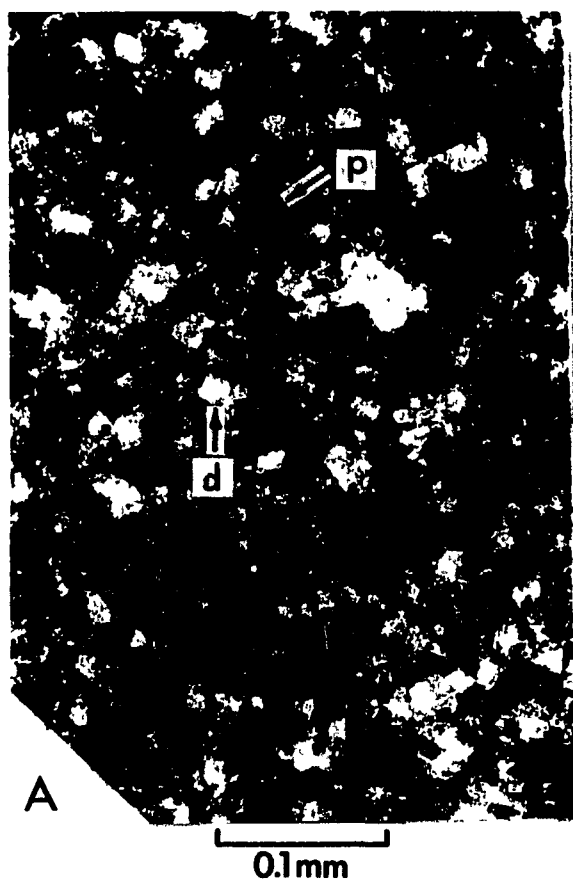


FIGURE 16

matrix. Dolomite is a common constituent throughout the facies, and in every well examined, the dolomite content was found to increase toward the base of the facies. The size and morphology of the dolomite crystals vary considerably, from small irregular patches of dolomicrite to euhedral dolomite rhombs, 0.010 to 0.020mm in diameter, which occur randomly in the pelletoidal micrite. Where dolomitization is extreme (Figure 16B), micrite is recrystallized to microspar and appears as relic patches in the predominantly dolomite matrix. Siltsized detrital quartz is slightly more abundant in the dolomitic beds, but never accounts for more than five to ten percent by volume of the rock. Fossils were not found in any of the drill cuttings of this facies.

#### Superficial Oömicrite Facies

This facies is present only in the central and southern parts of the area, and overlies the pelletoidal micrite facies (Figure 13). In the northern part of the area, the facies was not identified in the only well from which drill cuttings were available, the Harris #1 Moore 10-12. Cuttings were not available in Harmony Field, but between Harmony Field and East Nancy Field, the facies was found in the Harris #1 Evans 4-4 (WC/Sec. 4, 1N-15E). From East Nancy Field, the facies thickens into the Goodwater Field area, and on the north flank of the structure, it underlies and is interbedded with the oölite facies. On the south flank of Goodwater Field in the Shell #1 Thomas, beds of the

superficial oömicrite facies are interbedded with the pelmicrite facies. In general, these two facies cannot be distinguished without the aid of thin sections, as each consists of beds which range from irregularly laminated or fine bedded to burrow mottled. Small spongy oncolites, which occur "floating" in the finer grained matrix, are common, but are usuayly difficult to see in hand specimen because the lack of differential coloration between the oncolites and the matrix.

Small superficial oölites and pellets are the dominant allochem types with lesser amounts of spongy oncolites, composite grains, oölites, and fossils. The superficial oölites (Figure 16C) range in size from 0.070 to 0.150mm, whereas the pellets are smaller and usually measure between 0.060 and 0.100mm. The spongy oncolites are smaller and more tightly packed (Figure 16D), than those described from the lower member of the Smackover Formation. They appear to be transitional between the loosely packed spongy oncolites (lower Smackover) and the dense oncolites found in the oncolitic superficial oolite facies.

#### Pelmicrite Facies

This facies is present only in the southern area and was identified in cores from the Goodwater Field and from drill cuttings in the North Schubuta Field. The facies is underlain and overlain by the superficial oolite facies and these two facies are interbedded in the Shell #1 Thomas

(Goodwater Field). The pelmicrite facies also occurs in the upper part of the section in the Shell #1 Johnston (Plate III), but lateral continuity of this unit could not be established in adjacent wells. In the cored section, the beds are similar in appearance to the superficial oomicrite facies except for the finer grained appearance. The facies is poorly bedded or irregularly bedded and commonly appears to be extensively bioturbated (Figure 17A, 17B). Algal-coated fossils (Figure 17B) and spongy oncolites are generally less prominent than in the superficial oolite facies.

This facies is distinguished from the superficial oomicrite facies primarily on the basis of thin section characteristics. Pellets are usually more poorly defined and are smaller in size than those described from the superficial oomicrite facies. The pellets occur both as packed grains with interstitial micrite and as sparse grains in a micrite matrix. They are usually deformed and appear to have yielded plastically during compaction, occasionally becoming indistinct (Figure 17C). Fossils are less abundant and are less varied than in the superficial oomicrite facies. Punctate brachiopods are the most common bioclast found in this facies, and these generally do not have the thick micrite coating which is so typical of the fossils found in the other facies. In addition, there is less dolomite in this facies than any of the other upper member facies. The dolomite usually occurs as rhombic-shaped outlines of micrite sized dolomite (Figure 17D).

FIGURE 17. Photographs: Pelmicrite Facies

- A. Conventional Core Slab. Very fine grained pelmicrite with burrow structures.
- B. Conventional Core Slab. Burrow mottled pelmicrite and algal coated fossils.
- C. Small pellets in pelmicrite rock, and detrital quartz grains (q) with euhedral overgrowths.
- D. Closeup of pelmicrite rock showing typical dolomite fabric. Rhomb-shaped dolomite (d) composed of numerous tiny dolomite crystals rather than single crystal rhombs. Brachiopod shell in upper right is not micrite coated.

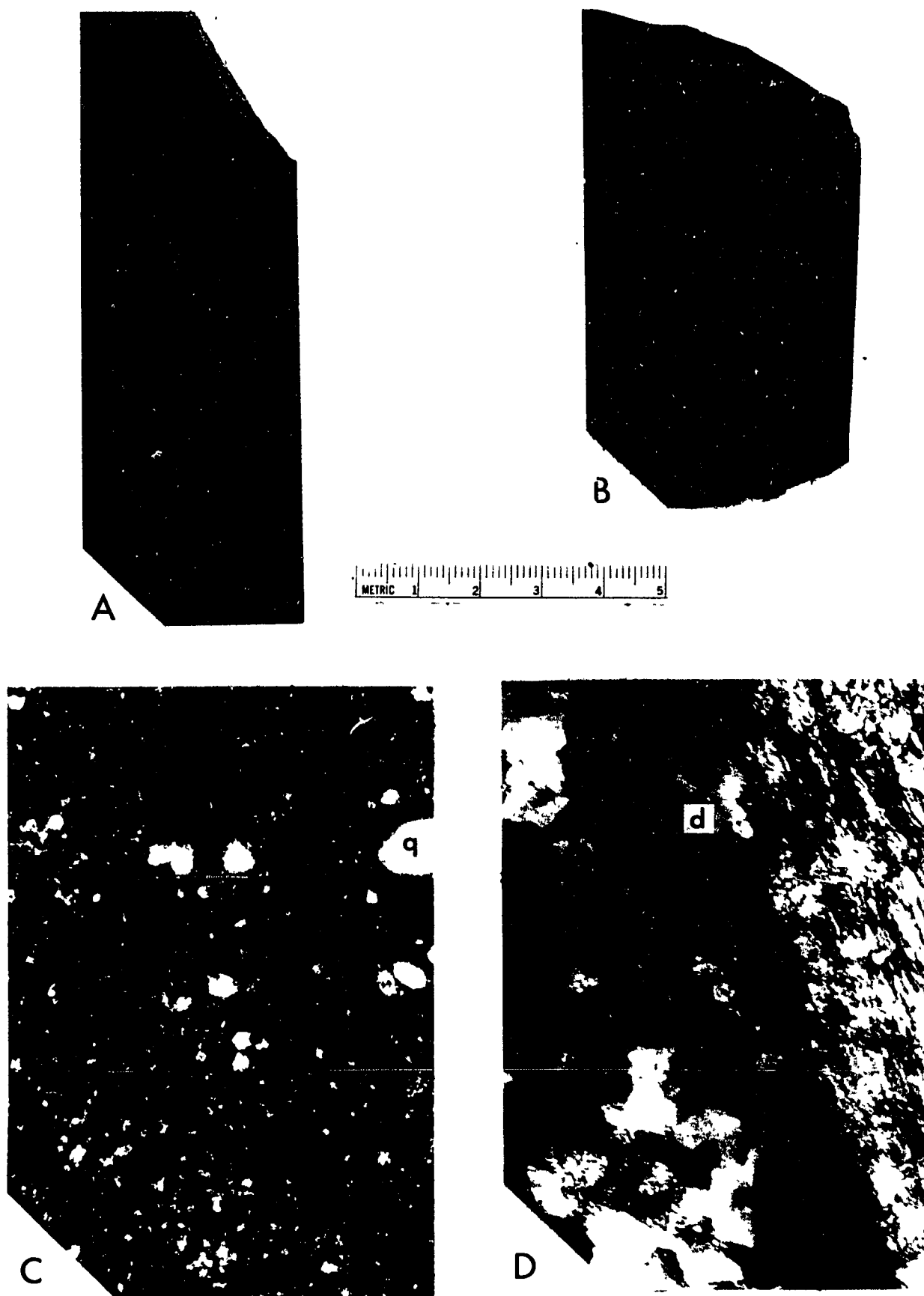


FIGURE 17

### Oolite Facies

The oolite facies is closely associated with the oncolitic superficial oolite facies and together they form the principal oil and gas reservoirs in the Smackover Formation. But, because the two facies have similar porosity characteristics, they cannot be differentiated by geophysical well logs and consequently can only be defined by drill cuttings and conventional core analysis. Throughout much of the area, the oolite facies consists of an upper oolite unit and a lower oolite unit which are separated by the oncolitic superficial oolite facies. These relationships can be seen on the stratigraphic cross section (Plate III) and on the schematic cross section (Figure 13). Along the line of section (Plate III), the oolite facies is present from Goodwater Field on the south to Harmony Field on the north, but may be absent in the area to the north of Harmony Field. The facies exhibits considerable variation across this area, both in petrology and relation to adjacent facies. To the south in Goodwater Field, the facies is interbedded with the superficial oolite facies, and in Harmony Field on the north, the facies is interbedded with the oolite-quartz dolomite facies. However, the facies relations appear to be fairly consistent in the east-west direction and the oolite "belt" is thought to extend eastward into Watts Creek and North Shubuta Fields and westward into Nancy and Pachuta Creek Fields (Figure 14). East Nancy Field, which is near the center of the oolite belt, is therefore a

convenient reference for discussion of the updip (north) and downdip (south) variations in the upper and lower oölite units.

The lower oölite unit is approximately one hundred feet thick in East Nancy Field where it overlies the superficial oömicrite facies and underlies the oncolitic superficial oölite facies. The lower unit consists of thick bedded homogeneous oolites in which stratification is usually not noticeable unless accentuated by the presence of the larger dense oncolites and algal coated fossils. Commonly thin beds of oncolites and fossils which appear to have been deposited as "lag" concentrates are interbedded with thicker beds of homogeneous oörites (Figure 18A). To the north, the lower unit is probably continuous into Harmony Field as oolite fragments were detected in drill cuttings from the Harris #1 - Evans 4-4 which lies between the two fields. In the downdip area (Goodwater Field), the oölite facies is poorly developed and characteristically interbedded with the superficial oömicrite facies. As no wells were drilled between East Nancy and Goodwater Fields, it cannot be determined if the facies is continuous between the two fields.

The lower oölite unit in East Nancy Field consists predominantly of well developed oörites with pellet nuclei although quartz nuclei are fairly common in sequences with high detrital quartz content. Superficial oörites are the next most abundant allochem and are always present giving



FIGURE 18. Photographs: Oölite Facies

- A. East Nancy Field, lower oölite unit. Fine grain oörites interbedded with "lag" concentrated layers of dense oncolites and algal coated fossils.
- B. Harmony Field, lower oolite unit. Small scale cross-stratified arenaceous oörites. The larger grains are primarily composite grains.
- C. Harmony Field, upper oölite unit. Thick bed of small dense oncolites, algal coated fossils and composite grains. Unit is interbedded with oolite beds.
- D. Harmony Field, upper oölite unit. Rare occurrence of spongy oncolites in oölite facies. Matrix composed of composite grains and oörites.

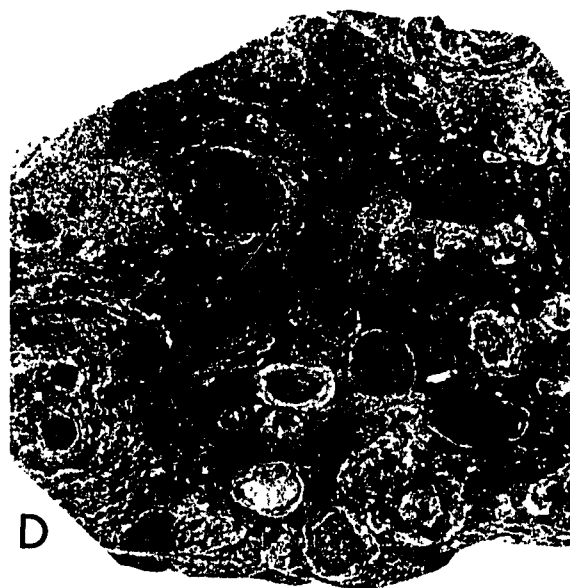
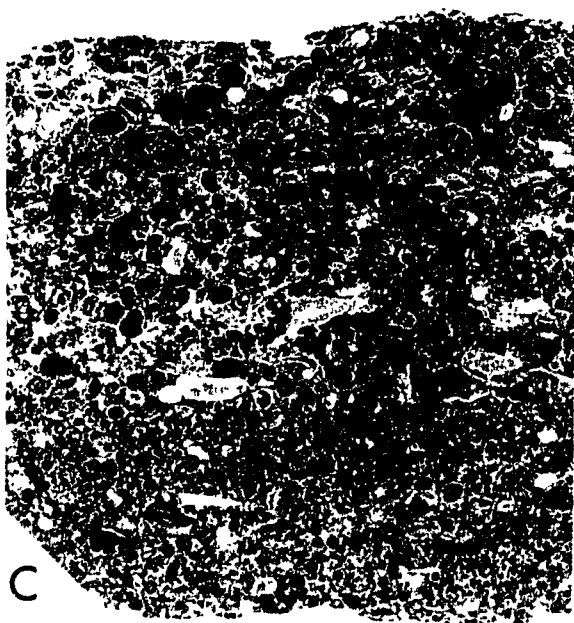
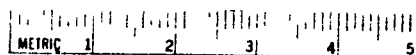
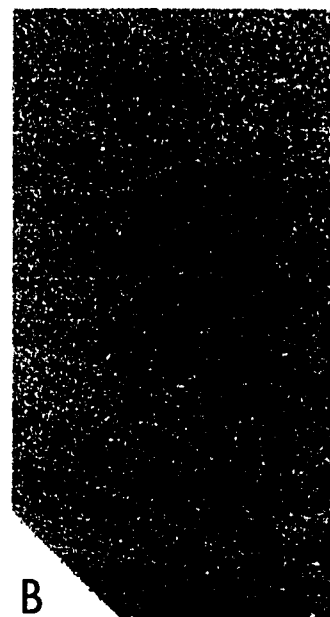


FIGURE 18

the rock a typical bimodal texture. Oncolites are exclusively of the dense type (Figure 19C) and are most frequently found where superficial oolites are a significant constituent.

The upper oölite unit in East Nancy Field is best developed in the reference well (Figure 15) where the unit is overlain by the oolite-quartz dolomite facies and grades downward into the oncolitic superficial oölite beds. At the top of the unit, the strata are fine bedded and are inclined at 10 to 15 degrees to the bore hole. Near the base of the unit, the beds are more coarsely bedded and stratification is essentially horizontal. In the upper part of the unit, dense oncolites are rare, but increase in abundance conspicuously near the base where the superficial oolite facies is interbedded. To the north in Harmony Field, the upper unit is quite different both in stratification and allochem types. The oölite beds are poorly stratified and contain thick beds of the larger allochems, dense oncolites, algal coated fossils (Figure 18C) and less frequently smaller composite grains and intraclasts. Near the top of the unit, thin beds of nodular anhydrite are commonly interbedded with the oölitic beds.

In the upper oolite unit in the East Nancy Field, the oölite allochems exhibit a distinctive vertical variation from top to bottom. Near the upper boundary, the oölitites are small (0.3 to 0.4mm) and well sorted, whereas near the base the oölitites are larger (0.8 to 1.0mm) and poorly sorted

because of the admixture of superficial oölites. Dense oncolites, fossils, and superficial oölites are common only near the base where the oolite beds interfinger with beds of the oncolitic superficial oölite facies. In Harmony Field, the upper oölite unit contains a distinctive variety of allochems which are generally unlike any found in the oolite beds to the south. Here the oölites are poorly developed and commonly contain two or more nuclei. Composite grains (botryoidal type, Illing, 1954) are the second most abundant allochem and are distinguished from the multiple nuclei oolites only by having a thinner coating. Intraclasts consisting primarily of micrite make up as much as twenty percent of the allochems in some beds and are notable because of their absence in oölite beds elsewhere.

The fossils found in the oölite facies are a typical marine assemblage consisting of echinoderms, algae (solenoparacean and codiacean algae), corals, bivalves, brachiopods, and gastropods. The fossils are almost always heavily coated with micrite which is thought to be algal in origin as a complete transition exists between fossils with thin micrite coating and oncolites with fossil nuclei. The process of micritization of grains by endolithic algae (Bathurst, 1966) which results in a micrite envelope around grains appears to have had some effect on the fossils. However, where the fossil fragment size is greatly increased, the process is clearly accretionary and probably due to algal encrustation.

The oölite beds appear to have been deposited with high

primary porosity as the rocks are essentially free of interstitial micrite. Subsequent compaction and pore-filling cementation have only partially reduced the porosity, and consequently these rocks are an excellent reservoir for hydrocarbons. The cementing materials are sparry calcite (calcspar), sparry dolomite (dolospar), and rarely anhydrite. These cements occur in six different fabrics in what is thought to be stages in a progressive sequence of cementation. Because a similar sequence was found in the oncolitic superficial oölite facies, the cements of both facies are discussed together under the section "Cementation of Oölite and Oncolitic Superficial Oölite Facies."

#### Oncolitic Superficial Oölite Facies

The oncolitic superficial oölite facies appears to be restricted to the central and northern parts of the oolite belt and was identified in cores from the East Nancy and Harmony Fields (Figure 13). To the south in Goodwater Field, the facies does not appear to be present although small superficial oölite beds are occasionally interbedded within the oölite facies.

The facies can be distinguished from the oolite facies by finer grain size and abundance of oncolites and algal coated fossils. The overall appearance of this facies is one of alternating beds of superficial oölites and thinner beds of packed oncolites and algal coated fossils. The oncolite beds range from one grain thick to as much as one

meter thick, but most commonly measure several centimeters in thickness (Figure 19A). The thicker superficial oölite beds usually have prominent dense oncolites and algal coated fossils floating in the superficial oolite matrix (Figure 19B).

The most common allochem types in order of abundance are pellets, superficial oörites, dense oncolites, oörites, and algal coated fossils. The superficial oörites always result from oölitic coating of pellets, and these two allochems are always found together. Both the superficial oörites and pellets are very uniform in size, ranging from between 0.080 to 0.150mm in diameter. It should be noted that the superficial oörites and oörites do not constitute a continuous oölitic series, but rather when found together, the resulting texture is strikingly bimodal (Figure 19D). Evidently the environmental conditions responsible for formation of the superficial oolites were distinctly different from that of the oölite facies. Also the superficial oölite facies appears to represent conditions most suited for oncolitic growth, as the dense oncolites here are both larger and more abundant than in the oolite facies. The nucleus of the oncolites are usually fossils or pellet aggregates, but many appear to have no discrete nucleus. Fossils are always algal coated (Figure 19B), and occasionally make up as much as 20 to 40 percent of the allochems in the packed oncolite beds. A continuous oncolite series is present from algal coated fossils (where the oncolitic

FIGURE 19. Photographs: Oncolitic Superficial Oölite Facies

- A. Typical Appearance of Superficial Oölite Facies. Small beds of dense oncolites and algal coated fossils alternating with beds of superficial oörites.
- B. Thick Bed of Dense Oncolites and Algal Coated Fossils. A complete transition exists between algal coated fossils and dense oncolites with fossil nuclei. Shapes of oncolites are frequently controlled by shell nucleus. Large radist at center left.
- C. Typical Texture of Oncolitic Superficial Oölite Rock. Laminations are not apparent in large oncolites (compare with spongy oncolite texture, Figure 16D). Oncolites are packed with matrix composed of superficial oörites and detrital quartz. Photographed in plane light.
- D. Internal Structure of Allochems and Fabric Controlled Cements. Dense oncolites at left exhibit crude oncolitic laminations, oolites at right have thick oölitic laminations, and smaller superficial oörites have thin oölitic laminations. Superficial oörites cemented by thin calcite crust (cc) in upper part, and oörites and oncolites cemented by blocky calcspar (bc). Note grain penetration more severe at oölite and oncolite contacts, but only slight at superficial oölite contacts.

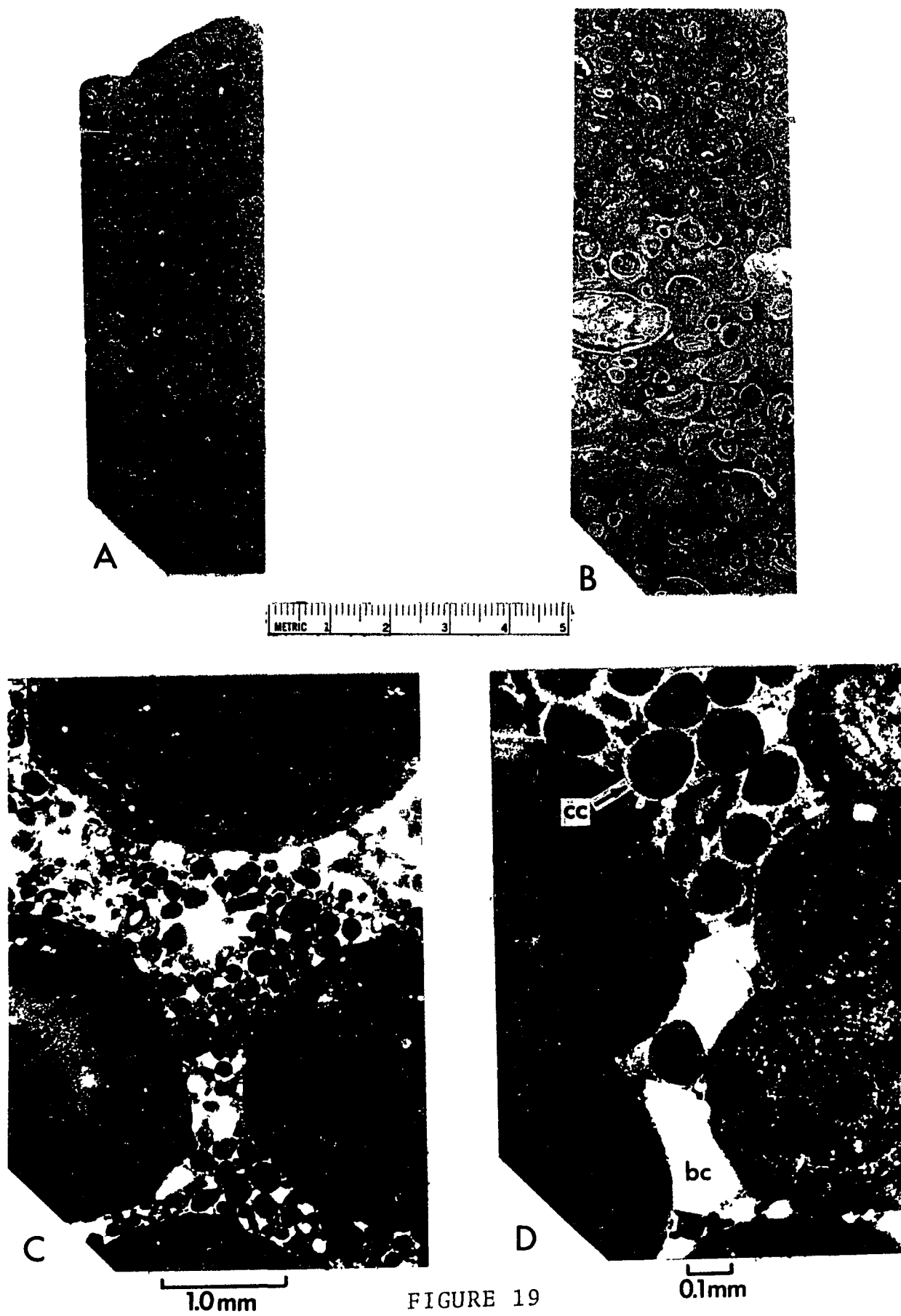


FIGURE 19



coating is less than one-third the radius of the fossil nucleus) to dense oncolites (where the coating is greater than one-third the radius of the nucleus). The most frequently occurring fossils are algae including Solenoporoaceae and Codiaceae. Other fossils less commonly found are echinoderm plates and spines, high spired gastropods, and bivalves.

#### Oölite-Quartz Dolomite Facies

This facies is restricted to the uppermost part of the Smackover Formation and underlies the lower member of the Buckner Formation. The stratigraphic position of the facies and its relation to adjacent facies is illustrated in Figure 13. In the East Nancy Field, the oölite-quartz dolomite facies overlies the upper unit of the oölite facies; in the Harmony Field, the facies overlies and is interbedded with the oölite facies; and in the most northerly well (Harris #1 Moore 10-12), it overlies the basal pelletoidal micrite facies. The facies does not appear to be present in Goodwater Field near the southern boundary of the study area.

The rocks which make up the oölite-quartz dolomite facies are composed primarily of dolomite, with variable amounts of oölites and detrital quartz. Because of the high dolomite content, the strata are usually lighter colored than the other facies of the Smackover Formation. Stratification is poorly developed and the rocks are typically wavy or irregularly bedded (Figure 20) but occasionally

## FIGURE 20. Photographs: Oölite-Quartz Dolomite Facies

- A. Algal Laminated Dolomite. Typical gradation from nonlaminated oölitic dolomite at base into probable algal laminated dolomite. The algal lamination in turn grades into intraclastic dolomite.
- B. Alternating small beds of intraclastic dolomite and nodular anhydrite. Anhydrite nodules are closely packed and form a nodular mosaic outlined by seams of interstitial dolomite.
- C. Oölitic dolomitic micrite from Harris #1-Moore 10-12 showing typical mottled appearance. Darker patches are poikiloblastic anhydrite, (thin section Figure 21E taken from this slab).
- D. Irregular Bedded Dolomitized Oömicrite. Rock contains packed calcite oölite and interstitial dolomite (thin section Figure 21A taken from this slab).
- E. Massive Dolomitized Oömicrite. Packed calcite oolites and intrastial dolomite. Large irregular dark patches are clusters of lath-shaped poikiloblastic anhydrite.
- F. Arenaceous intraclastic dolomite with shale partings. Large intraclast are composed primarily of aphanocrystalline dolomite; matrix composed of very finely crystalline dolomite and sand-sized quartz.



FIGURE 20

appear as homogeneous or massive. Small beds of nodular anhydrite (Figure 20B) are commonly present, but these rarely exceed a few inches in thickness. Small zones of irregularly laminated dolomite (Figure 20A) are also associated with the nodular anhydrite and are very similar in appearance to algal laminated sediment reported by numerous authors from the modern intertidal and supratidal environments (Shinn, et al., 1969).

Several rock types are included in this facies: oolite and quartz bearing dolomites (less than ten percent grains in dolomite matrix), oölitic and arenaceous dolomites (between 10 and 30 percent grains in dolomite matrix), dolomitized oömicrite\* and dolomitic quartz sandstones (packed or grain supported oörites or quartz grains with dolomite matrix). Also present, but in minor amounts, are intra-clastic dolomite, nodular anhydrites in aphanocrystalline dolomite ( $< 0.004\text{mm}$ ) and oosparite beds. The basis for grouping these different rock types into one lithofacies is similarity of depositional texture and diagenetic alteration. The dolomite is fabric selective, in that it replaces only the matrix material and does not appear to affect the allochemical grains. This interstitial dolomite matrix which is characteristic of all of the rock types except the oosparite is thought to be an early diagenetic replacement of lime mud (see section on Dolomitization of Oolite-

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\*Term used to describe replacement dolomite matrix between packed calcite oörites.

Quartz Dolomite Facies). Consequently, the rocks represent deposition under low energy conditions as suggested by Folk, 1962, p. 67, "Microcrystalline Allochemical Rocks." Additional diagenetic features which are common to the facies include dissolution (leaching) of calcareous allochems and subsequent void-filling precipitation of anhydrite, calcite, and sparry dolomite. The petrography of the most frequently occurring rock types is described below.

#### Oölite and Quartz Bearing Dolomite

In these dolomite beds, oolites and said size quartz are the most common grain types and occur floating in a matrix of very finely crystalline dolomite (0.005-0.016mm). The manner in which the oolites are altered diagenetically is the most characteristic aspect of these rocks. In this respect, they are identical with the mottled dolomite beds described from the Lower Smackover. At the base of the facies, the oörites are commonly dissolved (Figure 21B) giving the rock an oömoldic texture which is outlined by the interstitial dolomite. Higher in the section, the sites of former oörites are filled with either calcite, anhydrite, or less commonly dolomite. The calcite always occurs as single crystals (Figure 21D), and the anhydrite usually occurs as two or more prismatic crystals (Figure 21D). In the less common situation where dolomite fills the oörite site, the dolomite crystals are subhedral and tightly packed (Figure 11B). The single crystals of calcite are most

## FIGURE 21. Photographs: Oölite-Quartz Dolomite Facies

- A. Dolomitized Oömicrite. Calcite oölites (o) with interstitial finely crystalline dolomite. The dolomite is fabric selective, replacing probable lime-mud matrix.
- B. Oö moldic Fabric. Interstitial very finely crystalline dolomite (d), quartz grains and oölite molds (o). Early dolomitization of interstitial material and subsequent dissolution of oölites forming oölite molds.
- C. Closeup of dolomitized oömicrite. Calcite oölite with interstitial penetrating dolomite rhombs. Compare with Figure 23B (dolospa cement).
- D. Anhydrite (a) and single crystal of calcite (c) filling probable oö moldic cavities. Very finely crystalline dolomite (d) in the interstice.
- E. Typical diagenetic fabric in Harris #1-Moore 10-12. Interstitial material is microspar (m) and allochems are replaced by small crystals of dolomite (d).
- F. Poikiloblastic anhydrite. Lath shaped anhydrite crystals (a) replacing calcite allochems, but not interstitial dolomite (d).

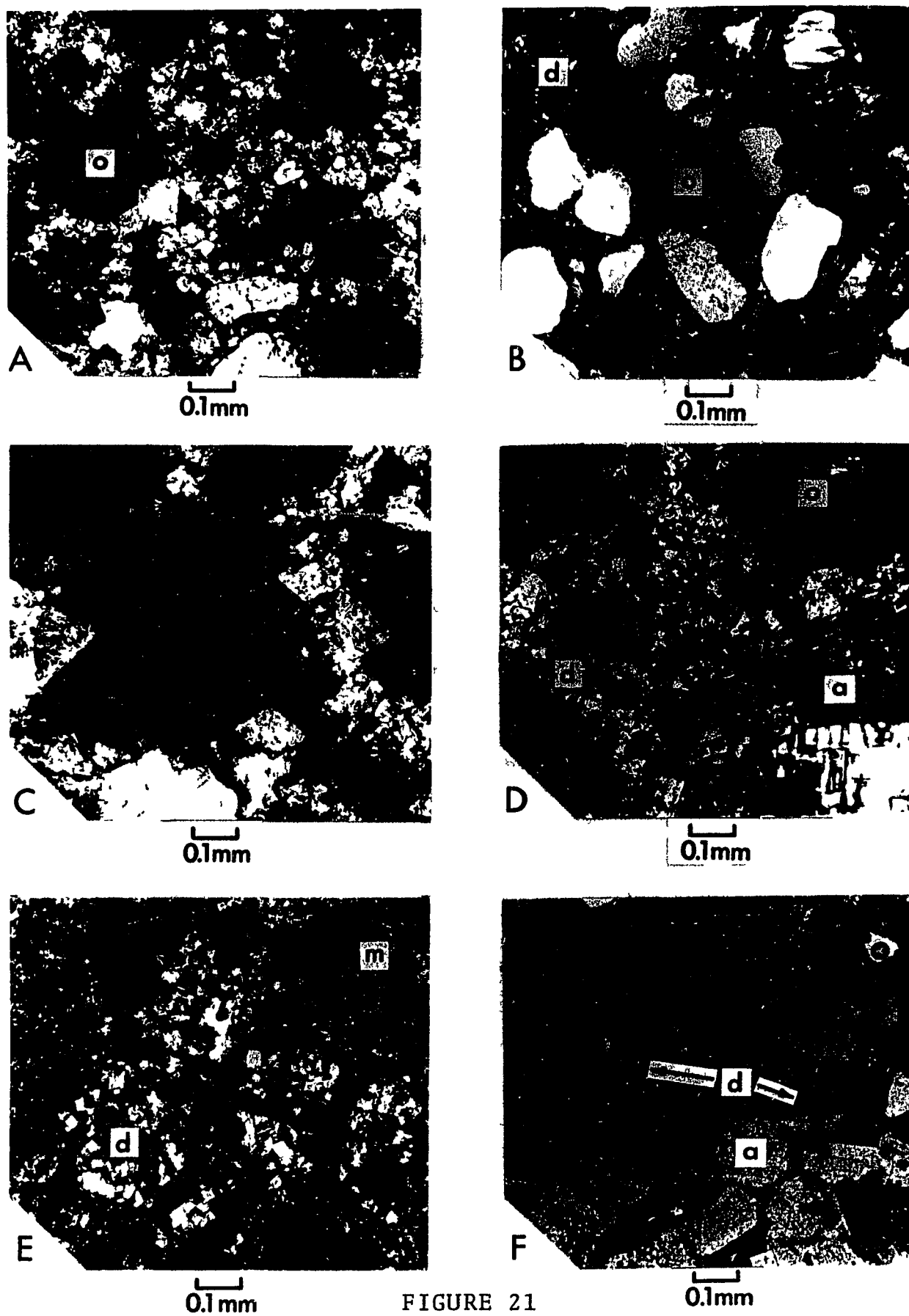


FIGURE 21

commonly found near the base of the facies whereas anhydrite is dominant in the upper part of the facies. It could not be established definitely whether the oölites were first dissolved (oölite molds) and subsequently filled by chemically precipitated cements; or that the anhydrite, calcite, and dolomite occurred by selective replacement of oölites. The presence of oölite molds at the base of the facies suggest that oolites throughout the facies were dissolved and later filled by chemically precipitated cements. This process may also explain the absence of fossils in this facies, although it should be noted that no fossil molds were identified. The time of dolomitization of the interstitial material is evidently prior to dissolution of the allochems as the molds are preserved by the surrounding dolomite.

#### Oölitic and Arenaceous Dolomites

In these rocks, the combined oolite and detrital quartz content is between 10 and 30 percent. Consequently, the grains are sparse (matrix supported) and occur floating in a very finely crystalline dolomite matrix. Where the oölites are a minor constituent (i.e., arenaceous dolomite), the original oölites are diagenetically altered to anhydrite, single crystals of calcite or sparry dolomite as described in the oölite bearing dolomites. Where oolites account for 20 to 30 percent of the grain content, the oölites are frequently as well preserved as those in the oölite facies.



Evidently the tendency for dissolution of calcareous oölites and subsequent void filling by anhydrite, calcite, or dolomite is related to the relative amounts of oölites present in the rock. As was noted in the oölite bearing dolomites, calcite casts are more common near the base of the facies whereas anhydrite casts predominate in the upper part of the facies.

#### Dolomitized Oömicrite and Dolomitic Quartz Sandstones

Dolomitized oömicrite refers to packed calcareous oölites with interstitial finely crystalline replacement dolomite (0.016-0.062mm). The term is used in order to distinguish between packed oölites with fabric selective dolomite matrix and packed oölites with chemically precipitated interstitial dolomite cement (oödolospar). Evidence for the interpretation of replacement dolomite is cited in "Dolomitization of the Oölite-Quartz Dolomite Facies" and criteria for distinguishing between replacement dolomite and dolomite cement are discussed. The size of the replacement dolomite in the packed oölite beds is generally larger (finely crystalline), than in the sparse oölite beds described earlier (very finely crystalline). The calcareous oölites are unaffected except for dolomite penetration at the outer edges of the oölites. Pressure solution at grain contacts is lacking, and finely crystalline dolomite completely fills the interstices (Figure 21A, 21C). Occasionally, large clusters of anhydrite crystals are present (Figure 20E,

21F) which replace the calcareous oölites but not the interstitial dolomite. Because these anhydrite crystals always contain dolomite inclusions, they are referred to as "Poikiloblastic" and should not be confused with the lensoid anhydrite (pseudomorphic after gypsum) described from the laminated micrite facies of the Lower Smackover.

In the dolomitic quartz sandstone beds, the grains consist primarily of sand-sized quartz with lesser amounts of feldspar and casts of allochems. The interstitial material is usually finely crystalline dolomite except where the dolomitic sandstone occurs near the top of the facies in which case anhydrite is equally abundant. The dolomite is thought to be a replacement of original lime mud matrix as is evidently true where the grains are sparse or "mud supported." In addition, the fabric of the dolomite crystals is similar to the dolomite crystals in the dolomitized oömicrite beds and differs significantly from the dolospar cement observed in the oölite facies. It is therefore probable that the dolomitic sandstone beds originally had a lime mud matrix with subsequent replacement of lime mud by finely crystalline dolomite.

#### Harris #1 - Moore 10-12

The dolomitic strata in the Harris #1-Moore which are included in the oolite-quartz dolomite facies are described separately because of their unusual diagenetic character. These rocks are thought to be part of the oölite-quartz

dolomite facies primarily because of the similarity of inferred primary depositional texture (oölite and detrital quartz with interstitial lime mud matrix). However, the character of diagenetic alteration is completely unlike that described for the oölite-quartz dolomite facies in wells to the south. The strata consist of alternating beds of sparse (Matrix supported) allochems and packed (grain supported) allochems in which the allochems are replaced by dolomite and the matrix is composed of microspar (0.005 to 0.030mm) and occasionally pseudospar ( $> 0.030\text{mm}$ ). The allochems are thought to be oölites because of their size, good sorting, and general spherical shape. Using the criteria for distinguishing between neomorphic calcite and sparry calcite suggested by Folk, 1965, p.44, it appears that chemically precipitated sparry calcite is not present. It therefore seems likely that these rocks originally had a lime mud matrix as was inferred for the rocks in the oölite-quartz dolomite facies to the south. On this basis, the dolomitized strata in the Harris #1 Moore well are included as part of the oölite-quartz dolomite facies.

#### Dolomitization of Oölite-Quartz Dolomite Facies

In this facies, the dolomite is referred to as fabric selective as it affects only the interstitial material and not the allochems. The dolomite consists of nonferroan crystals which range in size from aphanocrystalline to medium crystalline. However, three sizes are most frequently

found, aphanocrystalline (0.003-0.006mm), very finely crystalline (0.010 to 0.020mm), and finely crystalline (0.020 to 0.060mm). In this section, the origin of the fabric selective dolomite is considered as well as a possible explanation for the size ranges. In addition, criteria are established for differentiating between interstitial replacement dolomite and interstitial precipitated dolomite (dolospar).

The three dolomite size ranges appear to be related to primary depositional texture; aphanocrystalline dolomite is always associated with nodular anhydrite, very finely crystalline dolomite most frequently occurs as the matrix between sparse allochems, and finely crystalline dolomite is usually present in the interstices between packed allochems. In the case of the aphanocrystalline and very finely crystalline dolomites, the origin of the dolomite is more apparent. In these rocks, the allochems are usually dissolved and may appear as molds (moldic, Figure 21B) or as casts (Figure 21D) in which the casts are composed of single crystals of calcite, anhydrite laths, or less commonly large subhedral crystals of dolospar. Because the dolomite preserves the primary texture of the rock, dolomitization evidently occurred prior to dissolution of the allochems. The dolomite preferentially replaced the matrix material, but not the allochems which were dissolved during a later diagenetic phase. As these rocks have a "matrix supported fabric," it is probable that the dolomite preferentially replaced the

original lime mud matrix.

The origin of the fabric selective dolomite is less apparent in the packed or "grain supported" oolite beds because the oolites are as well-preserved here as in the oölite facies. For this reason, it is necessary that a distinction be made between interstitial replacement dolomite and interstitial precipitated dolomite (dolospar). Although differences in size are usually apparent, the manner in which the dolomite rhombs are oriented with respect to the oölite boundary is the most significant difference. As illustrated in Figure 21C, the typical orientation of replacement dolomite crystals is with the apex of the rhombs penetrating the oölite grain boundaries. This should be compared with Figure 23B from the oölite facies where the rhombs are usually oriented with the flat face parallel to the grain surface. Although exceptions to the general rule of small penetrating rhombs in the dolomite facies, and large nonpenetrating rhombs in the oölite facies were noted, the overall fabric contrast is striking. There were few thin sections in the oölite facies or the oölite-quartz dolomite facies which did not conveniently fit into one of the two dolomite fabrics. The interstitial penetrating dolomite is also considered to be replacement of lime mud, and therefore is referred to as dolomitized oömicrite. Evidence for this is afforded by the different kinds of oolite beds within the facies (dolomitized oömicrites and oösparite beds). In the oösparite beds, extreme pressure solution at

grain contacts is evident prior to precipitation of the calcspar cement. These beds were apparently well winnowed, with primary interstitial void space. By contrast, the adjacent oölite beds with interstitial dolomite show no grain penetration even when grains are closely packed. It would appear that these units were poorly winnowed with lime mud still present in the interstices. An alternate possibility is that the dolomitized oömicrite beds were cemented by dolomite prior to compaction. However, this idea is rejected because the oösparite beds which are adjacent to the dolomitized oömicrite beds show no evidence of dolomite cement. Also, the penetrating habit of the dolomite rhombs could be more easily accomplished if nucleation occurred within the lime mud matrix. In this manner, crystal growth could occur easily in all directions away from the nucleation site, resulting in penetration of the oörites during dolomite growth and replacement. By contrast the dolospar crystals indicate preferred growth into the interstitial void space.

Preferential dolomitization of lime mud in poorly winnowed calcarenites has been noted by many authors (Thomas and Gliester, 1960; R. D. Perkins, 1963; and Murray and Lucia, 1967). It seems most reasonable that dolomitization occurs early, before burial, while the lime mud is still porous. The process is of course enhanced where detrital dolomite is available to act as seed crystals and if magnesium rich fluids are available near the depositional site.

The origin of the aphanocrystalline dolomite is perhaps the most easily explained. Because of its close association with anhydrite nodules (see discussion of anhydrite nodules, "Depositional Environment of Lower Buckner Formation"), the aphanocrystalline dolomite is thought to be syngenetic, formed under supratidal conditions. Penecontemporaneous dolomite which is less than 0.005mm in size has been reported from the supratidal in the Bahaman area (Shinn, et al., 1965) and from the Persian Gulf area (Illing, et al., 1965). However, the reasons for the two larger dolomite sizes are more problematical. The very finely crystalline and finely crystalline dolomite sizes appear to be related to geographic position within the depositional environment; that is, proximity to the supratidal. If the relative percentages of oolites are used as an indicator of depositional current energy, then the oölite-bearing dolomites were nearest the supratidal environment. Therefore, the three dolomite size ranges appear to be related to geographic position at the time of deposition so that; aphanocrystalline dolomite occurs in the supratidal environment, very finely crystalline dolomite occurs in the proximal beds, and finely crystalline dolomite in the distal beds. As the dolomite is thought to be an early diagenetic replacement, it seems reasonable to assume that the source of dolomitizing fluids was the supratidal area where Mg-rich pore waters were concentrated. However, no explanation is apparent to explain the possible correlation between geographic position and

and dolomite size. Also, the relationship between dolomitization and dissolution of the sparse oölites is not clear. Because the two features are always found together, it suggests a common link. By contrast to the packed oblite beds in which the finely crystalline dolomite is both larger and less uniform, there is no evidence of dissolution of the calcite oölites. It is possible that these more distal units were less affected by refluxion of dolomitizing fluids (Adams and Rhodes, 1960).



## Depositional Environments of Upper Member of the Smackover

The pelletoidal micrite facies at the base of the upper member possibly represents a compacted pellet mud deposited under subtidal low energy conditions. Because this facies appears to be thicker and more widespread than the Lower Smackover facies, the pelletoidal micrites may represent more open marine conditions. However, the presence of fossils could not be definitely established as the facies was identified solely on the basis of drill cutting samples. The interbedded dolomite units appear to be related to proximity of the shoreline, as these are more common in the northern or updip wells. Evidence of shoaling, however, was found only in the most northerly well, the Harris #1 Moore 10-12 which contained small sparse allochems.

The superficial oömicrite facies overlies the pelletoidal micrite facies and is in part equivalent to the oölite facies updip and the pelmicrite facies downdip. In the vicinity of East Nancy Field, the superficial oömicrite facies is relatively thin and reflects a consistent change from subtidal low energy pellet formation at the base to high energy oölite sand at the top. The vertical increase in energy conditions may also be expressed by the upward decrease in lime mud matrix (micrite). The superficial oömicrite facies is considered to have been deposited on the seaward flank of the oölite shoals and in the Goodwater Field, deposition of the superficial oömicrite facies

persisted until near the end of the upper Smackover. The allochem types and presence of interstitial micrite indicate a poorly agitated subtidal environment in close proximity to shoal waters. The echinoids, bivalves, algae, brachiopods, and gastropods (Table III) suggest generally open marine conditions, and the thick algal coating of the fossils indicate at least intermittent agitation. Across Harmony Field to the north, data was not available so that the continuation of the facies could not be established. On the northwest flank of the field in the Exchange #1 Bufkin 6-7, the geophysical logs suggest "limestone porosity" over the interval 12400 to 12500 feet. If this log interpretation is correct, it is probable that shoaling conditions developed in this area, in a position updip from the superficial oömicrite facies.

The pelmicrite facies was encountered only in the Goodwater and North Shubuta fields, in the southern part of the area. As the facies consists of pellets and spongy oncolites with a predominance of micrite matrix, it is evident that the pelmicrite facies was deposited under lower energy conditions than the superficial oömicrite facies. From its position in the section (Plate III and Figure 13), it appears that the pelmicrite facies represents the deepest water deposition, basinward of the subtidal superficial oömicrite facies. However, the presence of spongy oncolites, and the relatively restricted macrofauna (predominantly brachiopods and echinoids) mitigates against open marine

TABLE III. Summary Chart, Petrology of the Upper Member of the Smackover Formation.  
\*Percentages based on visual estimates.

Percentages based on visual estimates.

LITHOFACIES	ALLOCHEM TYPE + DETRITAL QUARTZ Order of abundance * (Volumetric Ratio)				FOSSILS Order of abundance * (Volumetric Ratio)					MATRIX-CEMENT MICRITE/CALCSPAR/DOLOSPAR Order of abundance * (Volumetric Ratio)		
Oolite-Quartz Dolomite Facies	Oolites	Quartz	Intracrasts	--	---					Micrite replaced by early diagenetic dolomite		
Oncolitic Superficial Oolite Facies	Pellets	Superficial Oolites	Rounded Oncolites	Fossils Oolites	Algae	Echinoids	Gastropods	Bivalves		Calcspars	Dolomite Micrite	
Oolite Facies	Oolites	Superficial Oolites	Quartz Fossils Rounded Oncolites		Echinoids	Coral Bivalves Gastropods				Dolospar	Calcspars	
Pelmicrite Facies	Pellets	Spongy Oncolites	Fossils		Brachiopods	Algae Echinoids Bivalves Gastropods				Micrite		
Superficial Oomicrite Facies	Pellets	Superficial Oolites	Spongy Oncolites	Fossils Oolites	Echinoids	Bivalves	Algae Brachiopods Gastropods			Micrite	Calcspars	
Pelletoidal Micrite Facies	Pellets	Quartz			?					Micrite	--	--

conditions. Ginsburg (1960) noted that oncolites have not been reported from water depths greater than eight feet. Whether the pelmicrite facies is "basinal" or a restricted shelf environment cannot be determined within the study area.

The lower unit of the oölite facies was deposited in well agitated high energy shoals, and appears to form a linear band of deposits approximately ten miles wide and trending east-west across the study area. The generation of accretionary allochems evidently kept pace with basin subsidence, resulting in a thick sequence of oolite sands. The subtidal superficial oömicrite facies is considered to have been deposited on the seaward side of the oölite sand belt, and the oncolitic superficial oolite facies on the landward side in slightly deeper water with less vigorous agitation. The accretionary oolites formed under active tidal action on shoals developed parallel to the coastline. There is no evidence of a controlling shelf break in the study area such as that described from the present day Bahaman oölite belt (Ball, 1967). Rather the Smackover oölite belt appears to have built up as a consequence of the intersection of a gently sloping sea floor and wave base. The degree to which locally intrusive salt movement may have modified the bottom topography and oölite shoal morphology during this time is considered in the section on "Structure and Depositional History." The main body of the oölite facies (lower unit) is thought to be continuous from the

north flank of the Goodwater Field on the south through Harmony Field on the north. Goodwater Field is situated near the seaward edge of the belt, as the area is dominated by the subtidal superficial oomicrite and pelmicrite deposits. In the Goodwater area, high energy oolite shoal deposits are present only near the top of the Smackover Formation where the oolite bank prograded southward. In East Nancy and Harmony Fields, the lower unit of the oölite facies exceeds one hundred feet in thickness and evidently indicates equilibrium between deposition and subsidence. During rare periods of sustained subaerial exposure, beds of displacive nodular anhydrite were developed over the oölite shoals.

The oncolitic superficial oölite rocks were deposited landward of the oölite shoal banks and indicates less active current action. The current activity was sufficient for the formation of a thin oölitic coating on pellets, but apparently not vigorous enough to develop oölites. This moderately sheltered depositional area represents the most favorable site for growth of the dense oncolites, as these are much more abundant and larger than those found in the oölite facies. Evidently the blue-green filamentous algae which coated the free-lying grains require less vigorous agitation than that necessary for oölite growth.

The upper oölite unit in East Nancy Field which separates the superficial oolite facies from the oölite-quartz dolomite facies is thought to be a barrier beach deposit.

Sedimentary-dip angles of 10 to 15 degrees may represent beach accretion beds, indicating a relatively high energy beach. In Goodwater Field, the oölite beach does not appear to be present, and here the oolite-quartz dolomite facies is thin or absent. In Harmony Field, the upper part of the oölite facies varies considerably from that observed in the East Nancy Field and consists predominantly of composite grains and poorly sorted matrix. The composite grains are similar to the boitryoidal lumps described by Purdy (1963, Part 1), and probably represent early cemented aggregates with thin oölitic coating. These composite grains are thought to have been deposited in sheltered areas which lack appreciable bottom currents and probably with intermittent periods of bottom stability.

The various beds included in the oölite-quartz dolomite facies are thought to be deposited in a lagoon which formed landward of the barrier beach sequence. A protected low energy environment is evident from the dominant lithologic characteristics; mud supported allochems and terrigenous rocks with preferential dolomitization of the lime mud. Associated lithologies such as oosparite beds and dolomitized oomicrite beds are considered to be washover deposits from the oölite barrier beach. The intermittent small beds of displacive nodular anhydrite in aphanocrystalline dolomite matrix, were probably deposited in salt flats (sabkhas) which developed on emergent mud banks. These areas would be susceptible to formation of the

supratidal displacive nodular anhydrites which are similar to those forming at present in the supratidal sabkha flats of the Trucial Coast (Kinsman, 1969). Near the top of the facies, terrigenous grains are much more abundant and generally occur with grain supported fabric. This is thought to be a moderate energy wave exposed beach developed on the mainland side of the lagoon.

The distribution of Upper Smackover paleoenvironments is shown on the Schematic Summary chart, Figure 22. In this diagram, the basal pelletoidal micrite facies is not shown. This facies is thought to represent more open marine conditions than that indicated by the aerally restricted and vertically alternating Lower Smackover facies. It is possible that the pelletoidal micrite facies is part of a major marine transgression as the facies is thought to be present in the most northerly well, the Harris #1 - Moore 10-12 (Figure 13, Plate III). Upper Smackover rocks beginning with the superficial oömicrite facies represent a classic regressive sequence with progressive shoaling and continuous southward progradation of environments.

#### Cementation History of the

##### Oölite and Oncolitic Superficial Oölite Facies

The oölite and oncolitic superficial oölite facies were deposited under conditions which resulted in a well winnowed, grain supported sediment with high initial porosity. The depositional fabric is one of packed spherical

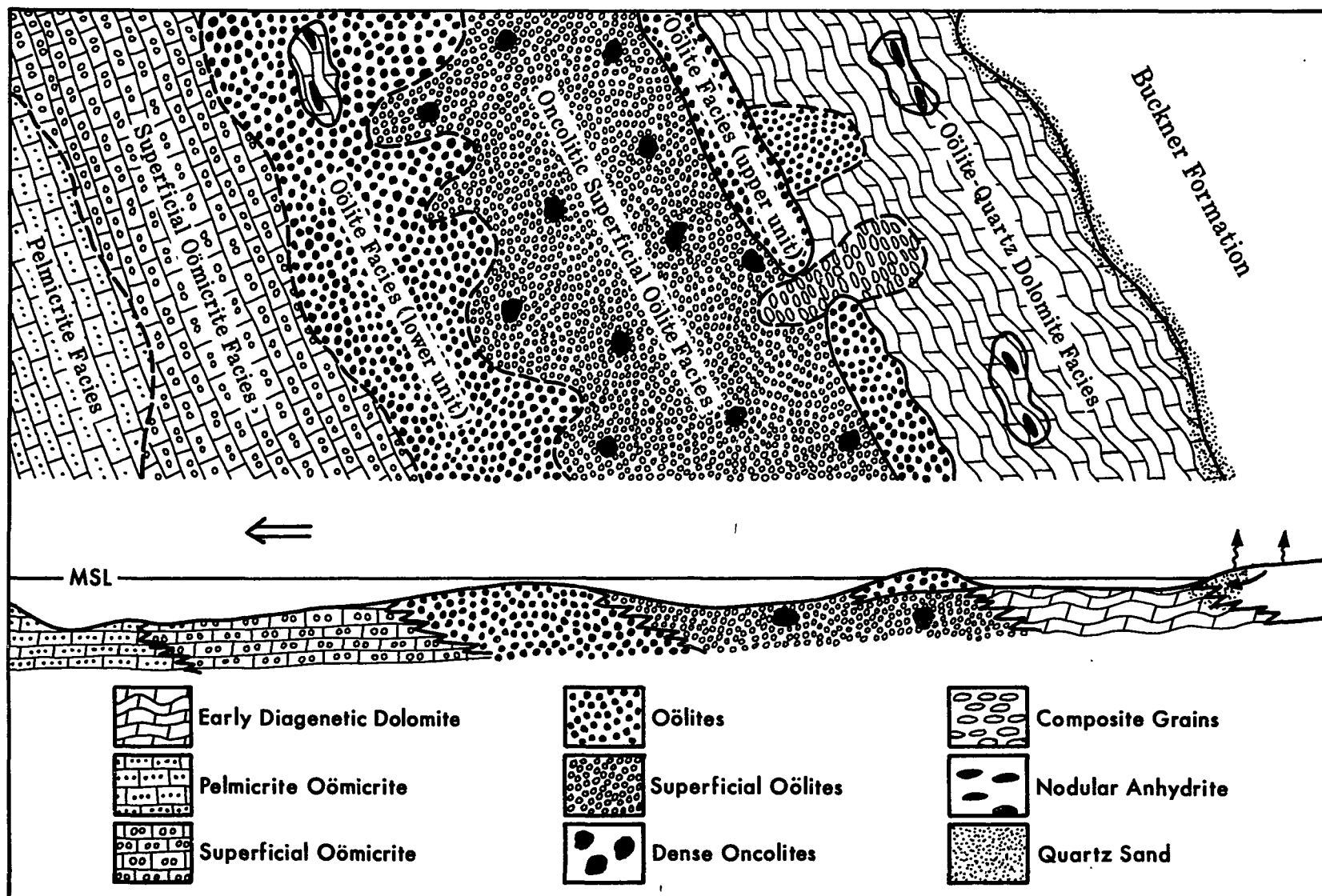


FIGURE 22. Schematic Summary of Paleodepositional Environments, Upper Member of the Smackover Formation



grains, with the size of the initial pore space dependent only on the degree of sorting and the size of the framework grains. According to the porosity classification of Choquette and Pray (1970), the porosity is primary depositional interparticle porosity. Subsequent cementation and associated diagenetic alterations appear to have occurred under continuous burial conditions--that is, without interruption by emergence (subaerial or vadose realm). Diagenetic features which would be expected if the offshore beds were exposed to vadose conditions (such as increase in dissolution of grains and fossils, and increase in amount of dolomitization) are lacking.

Chemically precipitated void-filling cements found in these facies are of five basic types: bladed calcite crust, euhedral dolospar, blocky dolospar, blocky calcspar, syntaxial rim cement, and possibly anhydrite cement. These cements are identified on the basis of mineralogy, crystal morphology, and relation to the foundation upon which the cement is built. R. L. Folk (1965) described a code for diagenetic calcite based on mode of formation, crystal shape, crystal size, and foundation. For the reader familiar with Folk's diagenetic code, the Smackover cements correspond to Folk's code in the following manner:

Bladed calcite crusts	PB <sub>2</sub> C
Euhedral dolospar	PE <sub>34</sub> C or PE <sub>34</sub>
Blocky dolospar	PE <sub>45</sub>
Blocky calcspar	PE <sub>45</sub>

## Syntaxial rim cement

PE<sub>36</sub>Om

In the discussion which follows, the cement types are described and the sequence of cementation is outlined.

### Description and Distribution

#### Bladed Calcite Crust

The calcite crust consists of bladed crystals of sparry calcite which are arranged radially around allochems (Figure 19D, 23A) and along the internal chambers of gastropods. Individual crystals are small, 0.005 to 0.010mm in length with an average length to width ratio of 3:1. Commonly, the crystals are merged into a circumscribing "halo" in which individual blades are indistinct. Where the crusts are well developed, evidence of compaction either by breakage or grain penetration is lacking.

Bladed calcite crusts are typically associated with superficial oölites in which the initial pore space is relatively small, and where the beds are well sorted calcite crusts are generally the only cement present. Because the crusts are thin (0.010mm), cementation is seldom pervasive and much of the pore space remains open. In larger pores, where oölites and dense oncolites form the framework, calcite crusts are usually absent. The allochem surfaces here appear to be leached or slightly corroded, and grain contacts show slight to moderate grain penetration. Similarly where grain penetration is extreme as in the upper oölite unit (beach) and the oösparite beds of the oölite-quartz

dolomite facies (lagoonal sequence) there is no evidence of bladed calcite crusts.

#### Euhedral Dolospar

Euhedral dolospar (Figure 23B) occurs as small rhomb-shaped crystals of sparry dolomite which line the free surface of pore spaces. Unlike the bladed calcite crusts which form a continuous encrustation, the individual dolomite rhombs are usually not in mutual contact and frequently occur as widely spaced crystals (Figure 23B). The crystals are seldom greater than 0.100mm, with 0.050mm being the average size. When compared with the replacement dolomite described in the dolomite facies, these crystals are characteristically oriented with the flat face of the rhomb parallel to the surface of the allochem. Where euhedral dolospar is the major cement type, the crystals filling the void are randomly stacked and resemble a disordered "pile of bricks." The allochem foundation is usually free of calcite crusts and only occasionally does the surface appear leached or slightly corroded. It should be noted that the allochems associated with dolomite cement are essentially free of replacement dolomite, and it appears that dolomite in this case has a strong preference for precipitation as cement rather than replacement of calcite allochems. This is contrary to the observation of Murray and Lucia (1967), who reported that dolomite shows a preference for replacing calcite rather than to grow as cement.

FIGURE 23. Photographs: Cement Types in Oölite and Supervicial Oölite Facies.

- A. Three Stages of Cementation. Small bladed calcite (cc) forming crust around superficial oörites and larger allochems. Several small crystals of euhedral dolospar (ed) are adjacent to calcite crusts. The larger interstice is completely filled by a single crystal of calc-spar (sr) at extinction (probably syntaxial rim cement). Note that the superficial oörites with bladed calcite crust show no grain penetration.
- B. Euhedral Dolospar and Blocky Calcspar. Oölite pore space is lined with small euhedral dolospar rhombs (ed). The typical orientation of euhedral dolospar is with flat face of rhomb in contact with surface of oölite. Large blocky calcspar crystal (bc) completely fills remaining pore space. The leading edges of some of the dolospar rhombs are partially replaced by calcite.
- C. Blocky Dolospar and Anhydrite. Large blocky dolospar (bd) appear white in photograph and two crystals of anhydrite (a) appear grey. This is the typical position for anhydrite, and is probably replacing blocky calcspar cement.
- D. Blocky Calcspar Cement. Oörites with moderate grain penetration are cemented by single crystal of calcspar (bc). The oölite surfaces in open void (v) are corroded to greater extent than oölite surfaces in contact with cement.

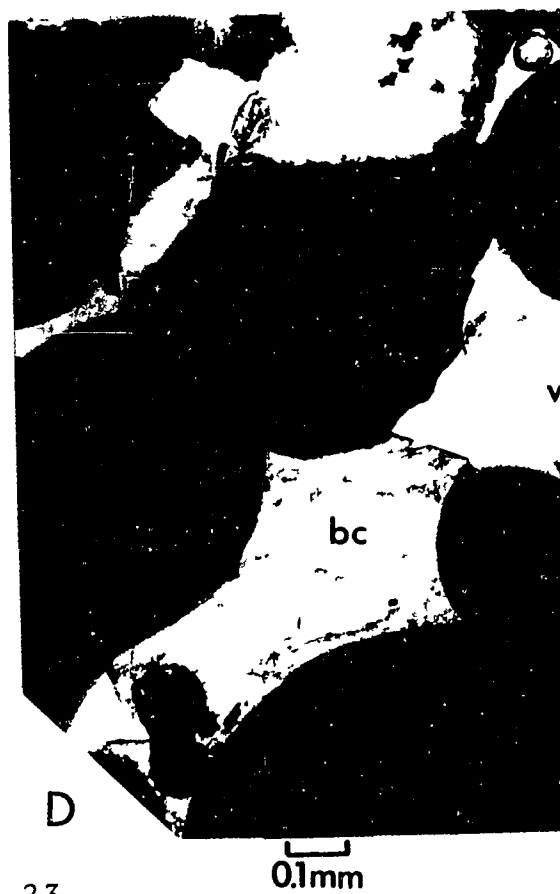
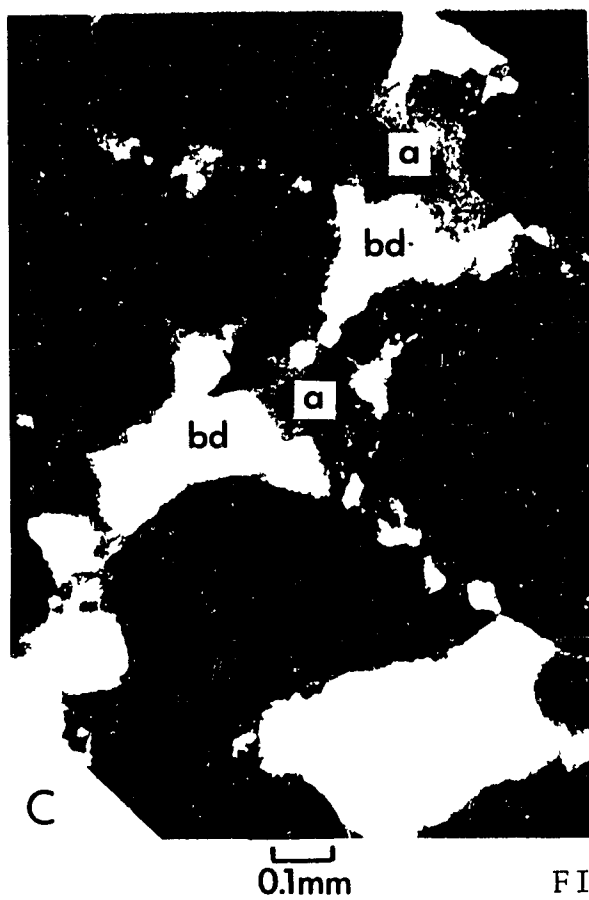


FIGURE 23

The euhedral dolospar cement is closely associated with oolite and oncolite beds where the initial pore space is relatively large. Cementation by euhedral dolospar is seldom pervasive, and characteristically several small crystals line the void with later cement types filling the remaining void space (Figure 23B). Euhedral dolospar is common throughout the lower oölite unit, and to a lesser extent in the coarser beds of the oncolitic superficial oölite facies. In the East Nancy Field, it appears to be absent from the upper oölite unit (beach), and from the oösparite beds within the oölite-quartz dolomite facies (lagoon).

#### Blocky Dolospar

Blocky dolospar occurs as large, roughly equant, crystals of sparry dolomite which tend to grow from one side of the pore void, commonly filling the entire pore space (Figure 23C). Therefore, the blocky dolospar is seldom euhedral as the crystal shape conforms to the shape of the pore space. In larger pores where several crystals are present, the boundary between crystals is always sharp and planar. Although blocky dolospar is described as a distinct cement type, it is more like one end member of the dolomite cement series, as all transitional varieties exist between small euhedral dolospar and large blocky dolospar. However, euhedral dolospar and blocky dolospar typically do not occur together in the same pore space.

It is not clear whether the blocky dolospar is simply a selective overgrowth of an earlier euhedral dolomite crystal, or that later blocky dolospar completely assimilates the earlier and smaller dolomite euhedra. Because the clear sparry dolomite does not show compositional boundaries, evidence of overgrowth versus dolomite replacing dolomite is lacking. The blocky dolospar crystals sometimes exhibits a sweeping extinction under cross-polarized light which is thought to result from curved crystal faces. A similar feature was reported by Choquette (1971), where it was described as a characteristic feature of some Mississippian dolomite cements. In the Smackover rocks, however, this feature was found to affect only a small percentage of the crystals.

The distribution of blocky dolospar is similar to the euhedral dolospar, but it is much more abundant. It is usually present to some degree in the beds with larger pore spaces, oölites and dense oncolites, and commonly constitutes more than fifty percent of the total cement. However, it is absent from the upper oölite unit (beach) and the oosparite beds within the lagoonal sequence.

### Blocky Calcspar

Calcspar cement occurs as clear sparry calcite crystals which are similar to the blocky dolospar in habit, and the two cements cannot be distinguished without chemical staining. Blocky calcspar is also pervasive, completely

filling smaller pores and occasionally single crystals extend through two or more contiguous pores (Figure 23D). Blocky calcspar and blocky dolospar frequently occupy the same pore space, in which case the calcspar appears to be precipitated after the dolospar. Where the two minerals are in contact, the boundaries may be either sharp or calcite is replacing dolomite (dedolomite) at the leading edge of the dolomite crystal (Figure 23B). Precipitated calcite is the usual form and shows a preference for growing as cement, as it replaces dolomite only where the growing calcite crystal impinges upon an earlier dolomite crystal. Dolomite replacing calcspar was not observed in any of the thin-sections from the oolite and superficial oolite facies.

The occurrence of blocky calcspar is similar to blocky dolospar and is found in beds with large pore spaces. However, in the upper oölite unit (beach) and in the oösparite beds within the lagoonal sequence, which are free of blocky dolospar, blocky calcspar is the only cement present.

#### Syntaxial Rim Cement

Syntaxial Rim Cement (Bathurst, 1958) occurs as sparry calcite overgrowths in optical continuity with the host grain, usually an echinoderm fragment or plate. Algal coating of echinoderm bioclasts seems to inhibit overgrowths when the thickness of the coating exceeds 0.070 to 0.100mm. For this reason although echinoderm bioclasts are common,



syntaxial rim cement is rare. These cements are significant because they are useful in interpreting the sequence of cementation. Syntaxial rim cement commonly preserves the first generation calcite crust, but its relation to the euhedral dolospar is more variable. Although several incidences were noted where the syntaxial rim cement postdated the development of dolospar cement (Figure 23A), the usual sequence is syntaxial rim cement followed by dolospar cement.

#### Anhydrite Cement

Anhydrite occurs both as true void-filling cement and as replacement of calcite host grains and calcite cements. But because replacement anhydrite seems to completely dissolve calcite host rock inclusions, the distinction between the two modes or origin is frequently indeterminant. Dolomite by contrast is never replaced and is usually present as inclusions (poikiloblastic) in the otherwise clear anhydrite crystals. Anhydrite occurs as elongate rectangular crystals (Appendix A4, Elongate Anhydrite Laths) or as subequant blocky crystals, and is either clear or poikiloblastic, depending upon the amount of dolomite inclusions. Individual anhydrite laths are commonly three to four mm. in length and extend across the allochems and pore space alike. The intervening allochems may or may not be replaced, and where no other cement is present the interstitial portion of the anhydrite crystal is true void-fill

cement. By contrast, the subequant anhydrite crystals usually occur in the center of the interstice in contact with the earlier dolomite cements (Figure 23C). In this "last event" position, the crystal shape conforms to the outline of the earlier cements. However, it cannot be determined if anhydrite is the last precipitate, or is replacing late sparry calcite. As the calcspar is essentially free of impurities, anhydrite replacing the sparry calcite would also be free of inclusions. For this reason it cannot be determined with certainty if the anhydrite is precipitated or is replacing calcspar. Anhydrite is ubiquitous in the oölite and superficial oölite facies, but always in relatively minor amounts.

#### Sequence and Origin of Cements

The varied cement types described above result from changing physical and chemical conditions brought about by burial to the present depth of 12000 to 15000 feet. The major cement types are considered to represent sequentially distinct stages, which reflect the changing diagenetic conditions. Ancillary features such as corrosion of grain surfaces and pressure solution at grain contacts are also important in defining the sequence of events and explaining the stratigraphic distribution of cement types. The compaction phenomena affords convenient criteria for separating early cementation from late cementation. Early cementation refers to cement precipitation prior to the development of

compaction features whereas late cementation refers to passive precipitation in the modified pore spaces.

### Early Cementation

Bladed calcite crusts were apparently the first cement to form as the crust is always found lining the free surface of allochem pore spaces. The calcite crust is thought to be an early diagenetic stage of cementation because it appears to have preceded the development of compaction features. Evidently the calcite crusts which envelop allochems prevented adjustment packing and pressure solution at grain contacts - features which should result from increased overburden pressure during burial. It should be noted that the calcite crusts represents a distinct first generation cement and is not continuous with the later pervasive blocky calcspar cement. Accordingly, the precipitation of the small amount of first generation calcium carbonate is separated in time from the later generations of cement as pointed out by R.G.C. Bathurst, 1971.

From the distribution of bladed calcite crusts (present is offshore superficial oölite beds, but not in beach and lagoonal oösparite beds), it appears most likely that the crusts were formed in the marine environment. The crystal fabric and general morphology of the crust is similar to the "isopachous" cement described by Land (1971) from a Pleistocene calcarenite in which the cement was inferred to have formed in the marine phreatic zone. A similar

explanation for the bladed calcite crust is favored because cementation appears to have preceded the formation of compaction features. The distribution of the crusts is, however, somewhat problematical in that calcite crusts should also be present in the offshore oölite sands with large initial pore space. The variation in distribution of the calcite crust may be due to differing conditions during deposition and shallow burial. The work of Taylor and Illing (1969) and Shinn (1969) on the "hardgrounds" in the Persian Gulf have shown that submarine cementation is favored where the grains are not effected by strong bottom traction. By this mechanism, the oölites in the well agitated, high energy shoals could have remained noncemented while submarine cementation was occurring in the superficial oölite beds which were less effected by bottom traction. However, additional criteria that are thought to be useful for recognizing ancient "hardgrounds" (Shinn, 1969) such as borings and internal sediment were not observed in the superficial oölite beds. An alternate proposal which appears to be more reasonable is that selective dissolution of bladed calcite crusts occurred in the coarser grained oölite beds. Circulating connate waters would be channeled through zones with larger pore voids, resulting in selective dissolution of calcite crusts, whereas smaller pore voids would be zones of minimum fluid transfer, therefore minor dissolution. This view is supported by the observation that where rare syntaxial rim cement (calcite

overgrowth) is present in larger pore spaces (Figure 23A), the first generation bladed calcite crust is frequently preserved. This period of dissolution is envisioned as occurring during or after significant burial as evidenced by the degree of compaction induced prior to the next cementation stage. Dunham (1971) reported a similar distribution of cemented fine grained material and uncemented coarse grained material under vadose conditions. However, this mechanism is rejected for the Smackover oolite and superficial oolite beds because of the lack of evidence for an emergence stage. None of the criteria commonly cited as evidence of vadose conditions such as meniscus cement (Dunham, 1971), "gravitational" cement (Muller, 1971), and caliche crust (James, 1972) were found in the oolite and superficial oolite facies.

If the interpretation of bladed calcite crusts is correct, it could account for the anomalous cementation history of the well winnowed oolite beds in the upper beach and in the lagoonal sequence. In these beds, the oolites show extreme pressure solution and grain penetration with pervasive blocky calcspar as the only significant cement. The occurrence of oolites cemented solely by blocky calcspar can be explained if the  $\text{CaCO}_3$  is considered to be locally derived from pressure solution of noncemented allochems during burial. In this manner, calcite cementation could occur during or in the later stages of compaction stabilization, even while a period of noncementation or

dissolution existed in the laterally equivalent beds of the offshore sequence. The pervasive nature of the blocky calcspar would also act to occlude later dolospar cementation.

### Late Cementation

In the offshore beds, the effects of burial (such as grain penetration and breakage of structurally weaker grains) appear to have essentially ceased before precipitation of the later cements. These cements are more pervasive, and are commonly restricted to the zones which have large initial pore spaces. Although a general chronology can be established, there appears to be considerable local variation both in the relative amounts of each cement and to a lesser degree in the chronologic sequence itself.

Dolospar cement represents the first stage of late cementation, and occurs either as first generation euhedral dolospar with a second generation calcspar cement (Figure 23B), or as blocky dolospar with or without later calcspar cement (Figure 23C). Where blocky calcspar is the second generation cement, these two minerals clearly represent two distinct stages of cementation. In the case of blocky dolospar, however, the distinction is less clear because a continuous transition between the two dolomite cement types is common.

Blocky calcspar is considered to be the next stage of cementation, although a few exceptions to the general

sequence were noted where blocky calcspar apparently preceded precipitation of blocky dolospar. The distribution of calcspar cement appears to be controlled by the extent of earlier dolomite precipitation. Where the dolomite stage is represented by a few scattered first generation euhedral crystals, calcspar is the major pervasive cement, but where blocky dolospar is extensively developed, later calcspar is confined to the relic intercrystalline voids near the center of the interstices. No consistent relationship between the ratio of dolospar to calcspar could be determined in the offshore beds. Closer sampling, for instance, one thin section per foot may reveal some stratigraphic variation which would not be apparent in the sampling program used in this study.

The time of occurrence of the rare syntaxial calcite rim cement was found to be variable, sometimes preceding dolospar (early cementation) and in other cases following dolospar (late cementation). Implication of the subsequent anhydrite (replacement?) appears to represent the last event, and is confined typically to the center part of the interstices. In this position, it is thought to be primarily replacement of late calcspar cement, although a distinction between precipitated anhydrite and replacement anhydrite can seldom be made with confidence.

The sequence of progressive cementation and related diagenetic phenomena in the offshore porous beds is summarized in Figure 24. It is evident that late cementation

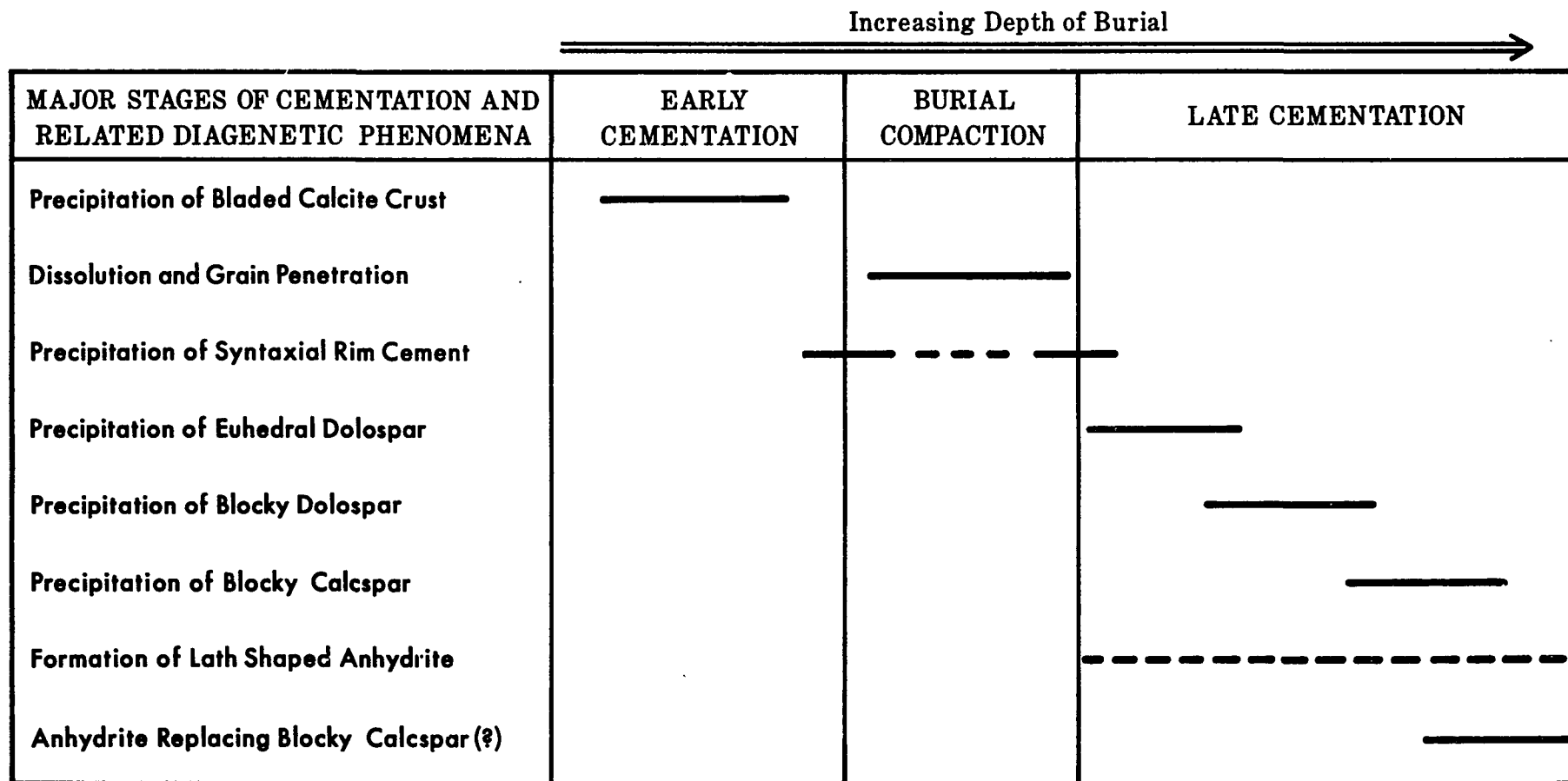


FIGURE 24. Outline of Progressive Cementation and Related Diagenetic Phenomena in Off-shore Oölite and Oncolitic Superficial Oölite Facies



occurred during advanced stages of burial, in response to the chemical and physical changes associated with significant burial. Since the late cements are concentrated in the more porous units, they appear to be the result of precipitation from migrating fluids in a regional deep groundwater system. The calcite cements in the porous upper beach and lagoonal beds were emplaced somewhat earlier. In these beds, a local source of  $\text{CaCO}_3$  is postulated--in part derived from the extreme pressure solution at grain contacts within the unit itself.

Very little is known about the mechanisms of subsurface cementation associated with deep burial. By contrast, surface and near surface cementation have been extensively investigated in the last few years. This disparity is due in part to the fact that petrologists usually work with surface outcrops in which it is difficult to distinguish between deep burial diagenesis (Mesogenetic Stage of Choquette and Pray, 1970) and diagenesis resulting from uplift and exposure at the surface (Telogenetic Stage). For this reason, the Smackover rocks are particularly well suited for the study of subsurface cementation as these were sampled (by conventional core) at very nearly their maximum depth of burial, 12000 to 15000 feet. However, the physical-chemical conditions responsible for the cementation events are not considered in this study. There is little information available on the chemical character of formation fluids associated with deeply buried carbonate

rocks, and to the writer's knowledge, no data is available on the Smackover rocks in Mississippi. Also the present formation fluids may be quite unlike the pore fluids from which the majority of the carbonate cements were precipitated. For these reasons, the late diagenetic cements are treated only in a qualitative sense.

The occurrence of nonferroan dolomite cements in the proportions found in the porous Smackover Beds appear to be unusual among sedimentary carbonate rocks. However, because the blocky dolospar and blocky calcspar are identical in habit, it is possible that much dolomite cement has been overlooked in the past. The dolomite cement is unrelated in time to the replacement dolomite described in the oolite-quartz dolomite facies. Whereas dolomitization in that facies was interpreted as early diagenetic, probably related to evaporative concentration, the dolospar in the offshore rocks developed during or after significant burial and is therefore later diagenetic. The origin of the magnesium in the volumes necessary raises some interesting questions as regards the diagenetic evolution of this part of the basin. From the distribution of dolomite, it is most likely that magnesium is derived from the basinal directions, as the shoreline sands are essentially free of dolospar cement. Diagenesis of basinal clay minerals as a source for magnesium has been proposed by Jodry (1969) to account for regional dolomitization. More recently, Choquette (1971) suggested dissolution of dolostone as a

possible source for regional dolomite cements. In the Mississippi Salt Basin, however, very little is known of the composition of the basinal rocks because of their extreme burial depths. Similarly the chemical character of the formation fluids have not been determined. However, from a cursory examination of the IES logs (resistivity of clean sands), it appears that the interstitial fluids are brines. Whether the brines result from deep burial diagenesis or dissolution of nearby piercement salt domes cannot be determined. It, therefore, is reasonable to conclude that the precipitation of late diagenetic dolomite cement in the Smackover beds is favored by high temperatures induced by the geothermal gradient during burial and high salinities (brines).

Although a specific study of cementation is beyond the scope of this project, certain observations can be made which relate to the general problem of subsurface cementation.

1. Pore filling cementation is by far the dominant diagenetic process occurring in the porous beds after compaction adjustment.
2. The cementation process is not continuous, but rather occurs in distinct stages. A possible exception to this is the dolomite stage in which euhedral dolospar may be continuous with blocky dolospar.
3. Periods of precipitation appear to alternate with

periods of dissolution, although no regular pattern could be established.

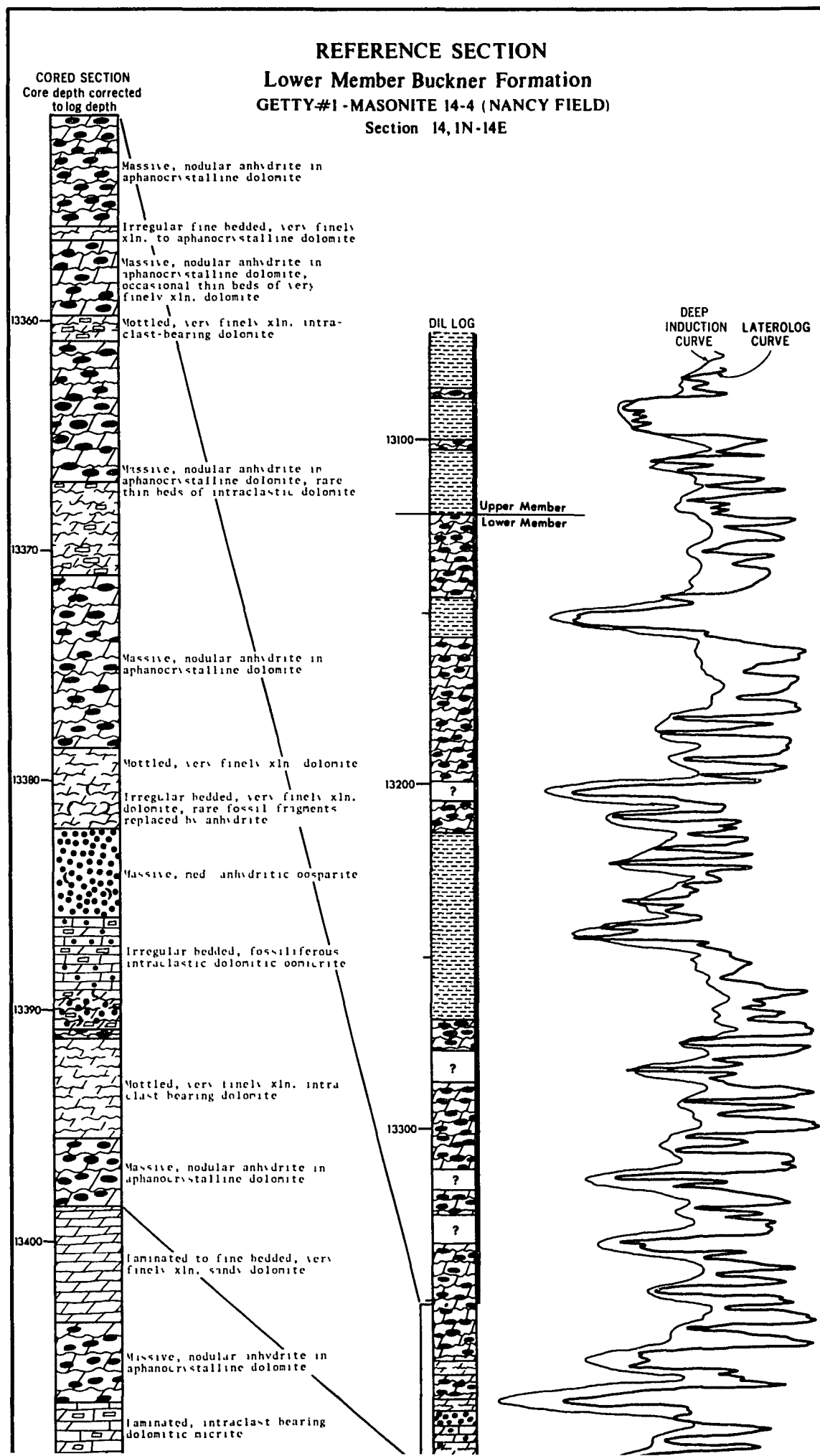
4. The source for most cement is thought to be outside the sedimentary body. Grain penetration and related dissolution phenomena within the carbonate sand bodies appear to be insufficient to account for the volume of precipitated cements.
5. The salinities of the formation waters at the time of precipitation were probably high (brines).
6. Chemical staining with potassium ferricyanide indicate that the carbonate cements are iron-free ( $\text{Fe}^{2+}$ ). This observation is rather surprising in the light of Evamy's work (1969) in which he suggested that reducing conditions prevail below the water table (phreatic zone). Under these conditions, ferrous iron is stable and therefore available for substitution in the carbonate lattice. The reasons for cementation only by nonferroan dolomite and calcite is not apparent as pyrite was identified in the Lower Smackover beds and it would seem likely that iron was also available in the Upper Smackover water system.

## LOWER MEMBER, BUCKNER FORMATION

The lower member of the Buckner Formation is included in this study because of its close stratigraphic association with the underlying Smackover Formation. However, cores were available only for the basal part of the lower member; therefore, the petrologic analysis is limited to this part of the section. Attempts to use drill cuttings to describe the entire lower member was hampered by extreme contamination from uphole cavings. Only one conventional core in the area was of sufficient length to be considered representative of the lower member (reference well, Getty #1 Masonite 14-4, Nancy Field), and the petrologic description is taken primarily from this well. Other cores in the lower member are less than 20 feet in length, and were used mainly to confirm the lateral continuity of the lithologies observed in the reference well (Figure 25).

### Stratigraphic Relationships

The lower member of the Buckner Formation overlies the Smackover Formation conformably and consists primarily of thick units of nodular anhydrite interbedded with smaller units of predominantly dolomite. The stratigraphic distribution of these units in the basal part of the member is shown on the stratigraphic cross section of the upper member of the Smackover Formation (Plate III). On the basis of geophysical well logs, individual dolomite units can usually be correlated between field wells, and occasionally



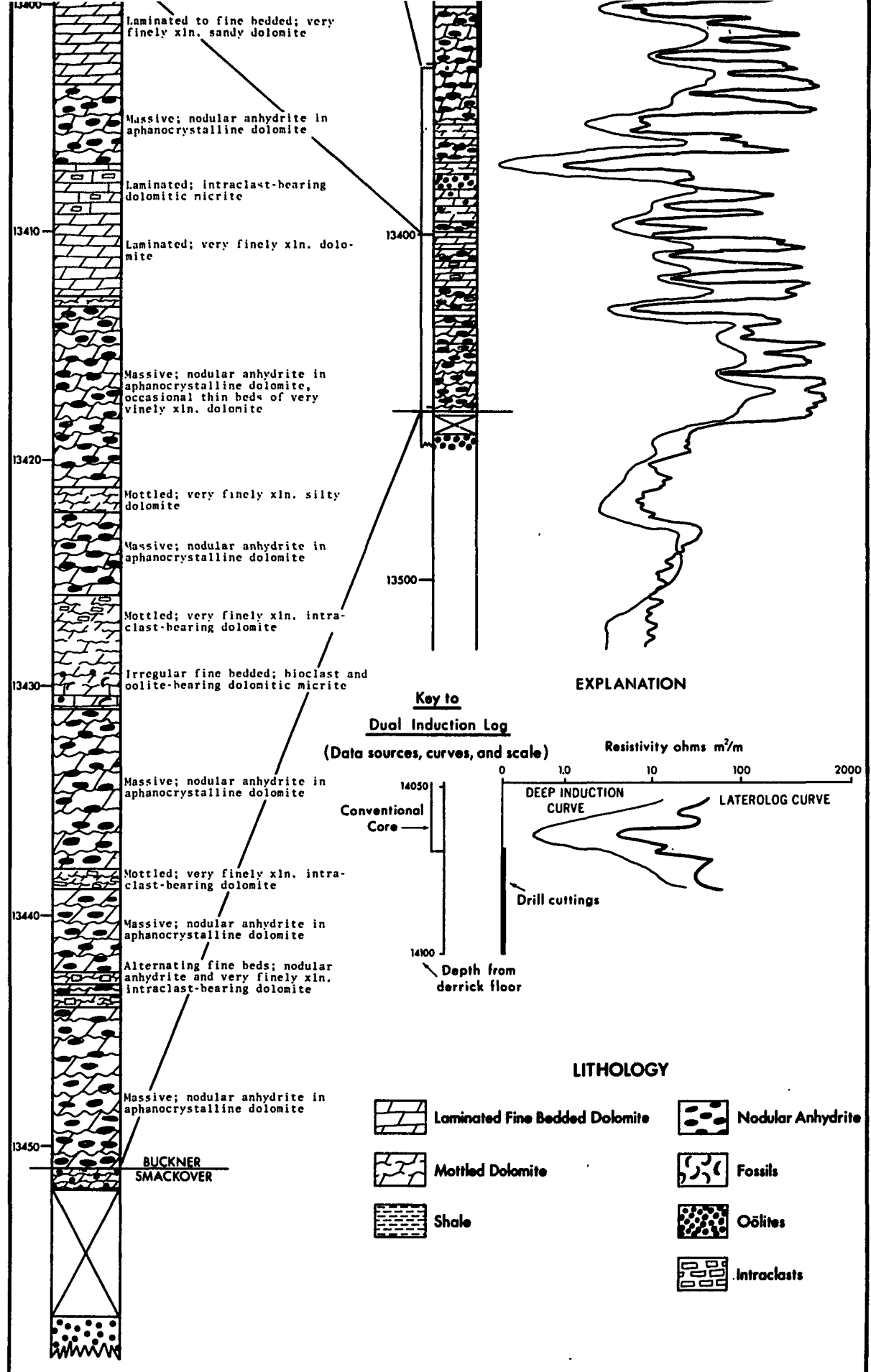


FIGURE 25. Reference Well, Lower Member of Buckner Formation

the dolomite units can be correlated between different fields, a distance of several miles. The dolomite units appear to be "lenticles" which lie within the more extensive nodular anhydrite rock, as they wedge out in all directions. The lower boundary between the Buckner and Smackover Formation was cored in several wells and is usually a sharp, easily defined contact (Figure 26B). The upper boundary of the member was not cored, but using geophysical logs and to a lesser extent drill cuttings, the contact appears to be transitional with the shales and quartz sandstones of the upper member. For mapping purposes, the boundaries of the lower member were defined by density log characteristics; the lower boundary was placed at the limestone-anhydrite break and the upper boundary was placed at the top of the uppermost thick anhydrite unit. Regional log correlations (DIL) indicate that the upper anhydrite beds are erratic in distribution, and as a result the upper boundary based on density log "picks" may not be consistent with regional electric log correlations.

The lower member is present throughout the area and ranges in thickness from 250 to 600 feet with an average thickness between 300 and 400 feet (Plate IV). Unlike the Norphlet and Smackover Formations, thickening and thinning of the lower member clearly reflects the influence of structural features associated with basin subsidence. The isopach map shows thinning over salt structures and thickening on the downthrown side of normal faults. These relationships



FIGURE 26. Photographs: Lower Member of Buckner Formation

- A. Nodular anhydrite mosaic. Irregular nodules of white anhydrite outlined by seams of dark interstitial aphanocrystalline dolomite.
- B. Contact between Smackover and Buckner Formations. Typical sharp contact between light colored, wavy bedded intraclastic arenaceous, oölitic dolomite (Smackover) and small nodules of anhydrite in dark colored aphanocrystalline dolomite (Buckner).
- C. Laminated dolomitic micrite at base of slab has large anhedral crystals of poikiloblastic anhydrite (see Figure 28F) which become less abundant as dolomite content increases upward. At the top, displacive growth of anhydrite distorts crudely laminated dolomite.
- D. Growth of anhydrite nodules in lower part have completely disrupted any primary structure. Parallel laminated dolomite in the upper part is undisturbed except for several small incipient anhydrite nodules.
- E. Nonlaminated micrite at base containing large crystals of poikiloblastic anhydrite grades upward into disturbed dolomite which contain small nodules of white anhydrite and dark "flakes" or clasts of aphanocrystalline dolomite.
- F. Small bed of disturbed intraclastic dolomite lying between thick units of nodular anhydrite mosaic.

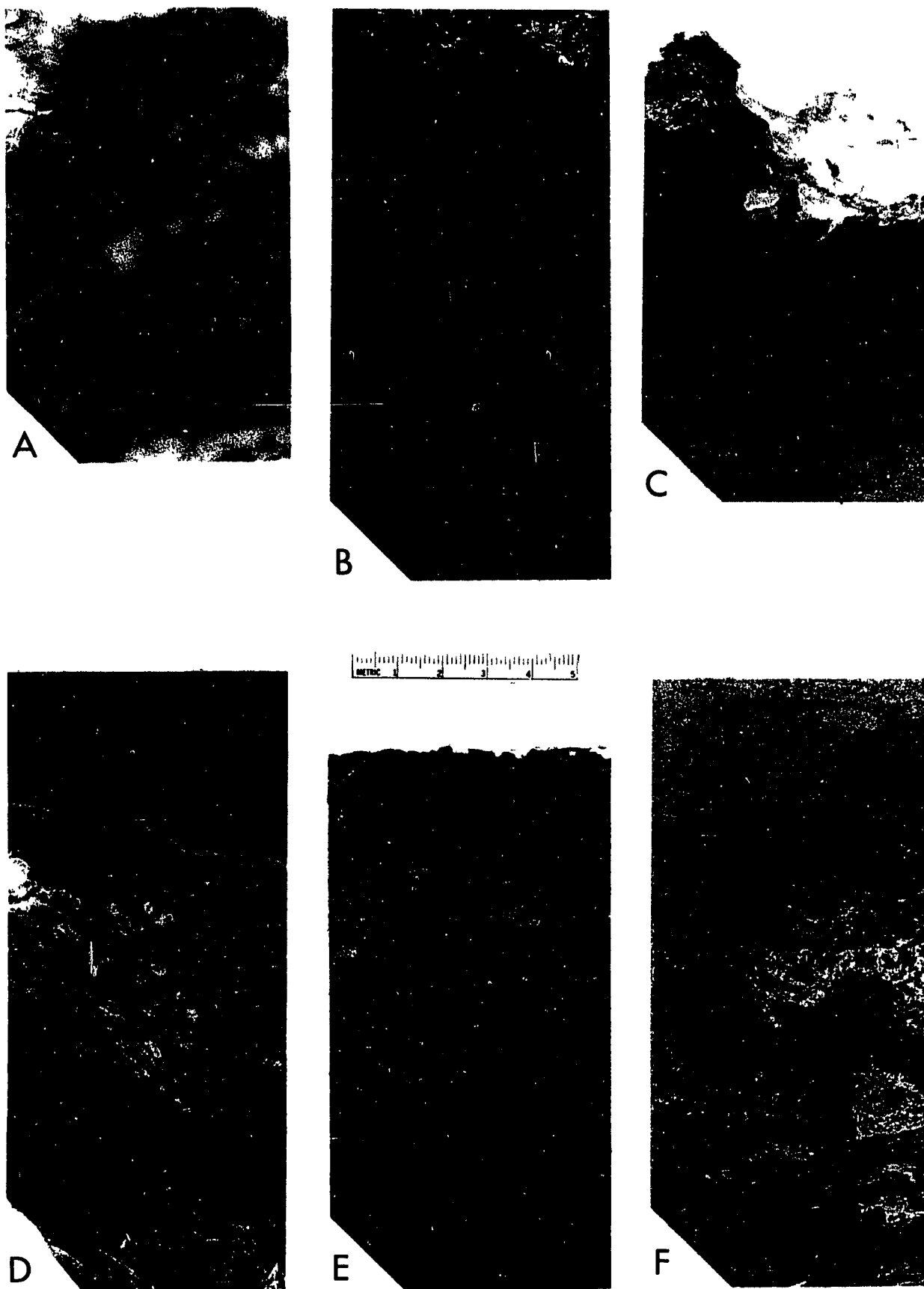


FIGURE 26

are discussed in more detail in the section on "Structure and Depositional History."

### Petrology

In the cored section of the reference well (Figure 25), the lower member consists primarily of two alternating lithologies, thick units of dolomitic nodular anhydrite, and thin units (lenticles) of laminated to mottled dolomite. Above the cored section, the interpretation of lithology is based primarily on the density log characteristics and secondarily on examination of drill cuttings in reflected light. Gray shales alternating with dolomitic anhydrite appear to be the principal lithologies. Near the top of the lower member, brownish shales become more common in the cuttings and the frequency of dolomite decreases. Pink anhydrite which probably results from iron impurities also is more abundant near the top of the sequence although white anhydrite remains dominant.

Based on the analysis of density logs and examination of drill cuttings in selected wells, the lithology shown on the reference well is thought to be representative of the lower member throughout the area. However, because so few conventional cores were available for study, the following petrologic description refers only to the rocks (nodular anhydrites and dolomite lenticles) found in the cored section of the reference well, Figure 25.

### Nodular Anhydrite Units

The nodular anhydrite beds are composed predominantly of white to grey anhydrite nodules with interstitial dolomite. Typically the nodules occur as an anhydrite mosaic where the nodules are closely packed and are separated by a thin film of dolomite (Figure 26A). These nodules are thought to be early diagenetic, formed by displacive growth in soft sediment. As a result of the accretionary growth, primary sedimentary structures are completely disrupted giving the rock a massive or homogeneous appearance. The massive anhydrite beds frequently contain thin zones of intraclastic dolomite (Figure 26F). The intraclasts are usually composed of aphanocrystalline dolomite and many appear as thin "flakes."

The anhydrite nodules (Figure 27A) are composed of numerous felted anhydrite crystals which range from 0.020 to 0.200mm in length. The anhydrite is essentially free of impurities such as dolomite and detrital grains and is probably an early diagenetic precipitate in soft sediment. The interstitial dolomite is extremely fine grained, 0.003 to 0.006mm in size, and typically homogeneous or nonstratified. Detrital quartz is the most common grain type in the dolomite and ranges in size from silt to fine sand. Rare occurrences of spherical casts (which are thought to be originally oölites) are always composed of large crystals of anhydrite, or less commonly large subhedral dolomite crystals. Near the bottom of the section, the frequency

of detrital quartz and allochem casts increases noticeably.

### Dolomite Units

The interbedded dolomite lentils are usually mottled, although occasionally laminated to fine bedded dolomite is present (Figure 26C, 26D). Associated with the dolomite are uniform beds of dolomitic micrite several inches thick, which commonly contain patches of replacement poikiloblastic anhydrite, giving the unit a false "birdseye" appearance (Figure 26E). Figure 26E is typical in that the micrite beds always grade vertically into dolomite (commonly intra-clastic) which in turn grades into nodular anhydrite. Also poikiloblastic anhydrite crystals appear to be restricted to micrite beds and nodular anhydrite to dolomite beds. In one of the dolomite units, a small four-foot oösparite bed is present (Figure 25, 13382-386) which is underlain by a burrowed oölitic micrite bed and overlain by mottled dolomite.

The dolomite beds are composed of euhedral to subhedral dolomite crystals which range in size from aphanocrystalline (0.003 to 0.006mm) to very finely crystalline dolomite (0.010 to 0.020mm). The aphanocrystalline dolomite usually occurs as clasts in a very finely crystalline dolomite matrix (Figure 27C). Where the dolomite is laminated, stratification sometimes results from textural variation of darker aphanocrystalline dolomite laminae and lighter very finely crystalline dolomite laminae (Figure 27B). In addition to

FIGURE 27. Photographs: Lower Member of Buckner Formation

- A. Nodular Anhydrite. Nodule composed of felty anhydrite crystals in ground mass of aphanocrystalline dolomite.
- B. Laminated Dolomite. Alternating laminae of aphanocrystalline dolomite (dark) and very finely crystalline dolomite (light) which contains silt size detrital quartz and anhydrite casts of allochems.
- C. Intraclastic Dolomite. Aphanocrystalline dolomite clasts (dark) and very finely crystalline dolomite matrix (light).
- D. Oösparite. Well developed oölites cemented by blocky calcspar (bc). In upper right, large crystal of anhydrite at extinction (a) extends into several interstices - the anhydrite is thought to be replacing calcspar cement.
- E. Dolomitic pelleted micrite with bivalve (?) shell.
- F. Oölitic micrite with large poikiloblastic anhydrite crystal. The anhedral anhydrite crystal contains inclusions of dolomite and is considered to be replacement of micrite.

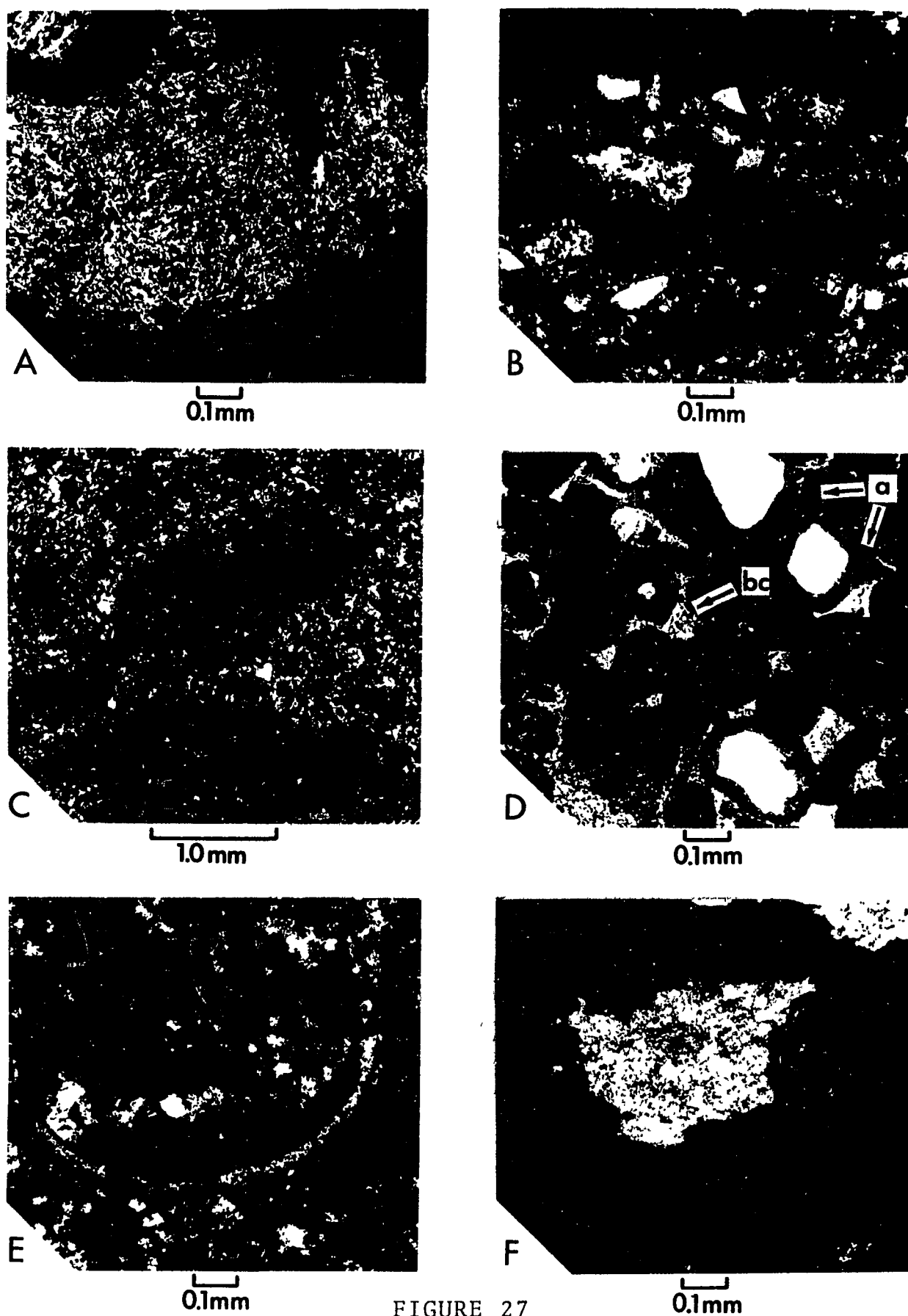


FIGURE 27

intraclasts, the dolomite beds commonly contain anhydrite allochem casts and silt and sand-sized detrital quartz. The micrite beds which are occasionally interbedded with the dolomite beds appear pelleted and contain a few disarticulated shells which are thought to be bivalves (Figure 27E).

#### Depositional Environment of Lower Member of the Buckner Formation

The interpretation of depositional environments of the lower member of the Buckner Formation is necessarily dependent upon the origin of the anhydrite nodules. These nodules evidently represent early diagenetic growth in soft sediment, not by replacement but by accretionary growth which displaced the original sediment. This is indicated by: (1) deflection of bedding planes around nodules; and (2) the absence of primary sediment impurities within the anhydrite nodule. Chemically precipitated anhydrite (or anhydrite after gypsum) from standing bodies of water which would form rhythmic anhydrite lamination were not found in any of the cores in the study area.

Nodular anhydrite with felted lath texture has been reported from Holocene deposits in the supratidal sabkha flats along the Trucial Coast (Shearman, 1966; Kinsman, 1966, 1969). Similar deposits have been described by several authors from inferred supratidal environments in ancient rocks (Murray, 1964; Wardlaw and Reinson, 1971). However, displacive anhydrite nodules have also been reported from



submarine cores of Holocene deposits at depths greater than 2000 meters in the Red Sea (Ross and Degens, 1969). In addition, Schmidt (1965) described nodular anhydrite from the inferred basinal facies of the Jurassic Saxony Basin in Northwestern Germany. Schmidt suggested that the salinity was higher in the deeper waters of the basins resulting in syngenetic development of displacive anhydrite in the unconsolidated basin sediments. A somewhat similar interpretation has been suggested for the Buckner anhydrite beds in Texas (Dickinson, 1968) which were described as deposited in a marginal evaporite basin. Dickinson proposed that the basin developed at the end of Smackover deposition with the marginal rise of salt cored anticlines which restricted the outflow of hypersaline water from the marginal basin (K. A. Dickinson, p. E15).

The Buckner anhydrite beds in the study area are thought to be supratidal deposits which formed in a subaerally exposed surface on the landward side of the Smackover lagoon. Evidence for this interpretation includes: (1) the occurrence of zones of intraclastic dolomite within the massive anhydrite units; (2) the striking similarity to supratidal deposits on the Trucial Coast; and (3) facies relations with the interbedded dolomite lentils and underlying Smackover lagoonal deposits. The small zones of intraclastic dolomite within the massive anhydrite beds are considered to be storm deposits caused by flooding of the coastal sabkhas during periods of high storm activity. The depositional

environment was probably similar to the present day coastal sabkhas in the Trucial Coast area, where evaporation from the sabkha surface causes interstitial pore-fluid concentration (Kinsman, 1969, p. 834). In this manner, the anhydrite nodules grow in the host sediment by physical displacement and are, therefore, early diagenetic minerals. The interstitial aphanocrystalline dolomite is also thought to be early diagenetic or prelithification dolomitization. Kinsman (1969) reported supratidal penecontemporaneous dolomite one to two microns in size associated with evaporite minerals in the coastal sabkha sediments. Algal laminated sediment which is frequently cited as evidence of supratidal deposition, is a rare occurrence in the Buckner anhydrite beds, but this may be due to the disruptive growth of the anhydrite nodules. However, the dark flake-like clasts (Figures 26E, 26F) may represent "rip-up" clasts of algal bound sediments from algal mats.

The interbedded dolomite lentils are best explained as deposits of lakes which developed within topographically low areas on the coastal sabkha flats. Salinities in the supratidal lakes was evidently not high enough to cause evaporite mineral precipitation (rhythmic laminae) from the standing water. The lakes were probably subject to periodic influx of relatively normal marine water which could account for the dolomitic micrite that is interbedded with the lacustrine dolomite. These lakes are envisioned as covering several square miles, as the dolomite units are commonly

correlative between adjacent fields.

The oölite beds represent a major marine transgression into the marginal portions of the coastal sabkhas. The oösparite bed may be a transgressive beach deposit which extended through the Nancy, East Nancy, Pachuta Creek, and Harmony Field areas. Correlation to the south in Goodwater Field is, however, very tentative and possibly at the time of the transgression, the Goodwater Field area lay seaward of the strandline.

## STRUCTURE AND DEPOSITIONAL HISTORY OF THE NORPHLET, SMACKOVER, AND BUCKNER FORMATIONS

The study area is located along the structural hinge-line which separates the central Mississippi High to the north and the Mississippi Salt Basin to the south (Figure 1). The large inferred fault "A" may be part of the hingeline system, as it forms the updip limit of the Louann Salt in this area. Basinward from the fault, the salt thickens rapidly, forming a wedge-shaped substratum (Hughes, 1968) upon which the Norphlet, Smackover, and Buckner Formations were deposited. During deposition of these rocks, the basin was deformed by both upward movement of the underlying salt mass (halokenesis) and tensional faulting. The presence of these structural features is based primarily on the thickness variations of the rock units as indicated by the isopach maps. In this manner, local thinning of a rock unit is inferred to be due to penecontemporaneous movement of the salt mass during deposition, and local thickening along the downthrown side of an inferred fault is thought to be the result of penecontemporaneous dip-slip movement (referred to as "growth" faulting). Because of this approach, later structural features which only act to modify the attitude of the older strata by flexure or fracturing are not considered. As deposition of the rock sequence is closely related to the structural events, these aspects are treated together under "Depositional History."

### Nature of the Substratum

The Louann Salt which forms the mobile substratum for upper Jurassic rocks is the least studied unit of the Jurassic sequence. For exploration purposes, the Louann is considered to be "basement," and therefore only the top is penetrated. In practice, the presence of salt is usually established by an increase in salinity of the drilling mud, at which point drilling is halted. For this reason although the "salt" is encountered in numerous wells, there is almost no information available on its lithology. The Louann Salt was not cored in the study area, and to the writer's knowledge, was not cored in this part of Mississippi. The Louann is usually described as being predominantly halite, but there is little physical evidence for this in the updip areas. If the northern limit of the Louann Salt in the study area represents a stratigraphic pinchout, considerable impurities such as fine grained detritus and sulphates would be expected. For that matter the hematitic and argillaceous carbonates (referred to as Eagle Mills?) which were found overlying Carboniferous phyllites in the Sun #1 Board of Supervisors 16-13 may in fact be an updip facies of the Louann. The question of whether the updip limit of the Louann Salt is a stratigraphic pinchout or a pre-Norphlet erosional limit will not be satisfactorily answered until more lithologic data is available.

The basement rocks over which the salt was deposited was described by Hughes (1968) as being a relatively flat

basinward dipping surface. The thickness of the salt is probably variable, with the thicker parts underlying salt cored anticlines and thinner parts lying between anticlines in the withdrawal areas. No data was available on the actual thickness of the salt, however, Hughes reported a thickness of two thousand feet for the salt underlying the crest of the Nancy Field structure. DeBartolo (1970), using seismic data, indicated a closure of three hundred to four hundred feet on the Nancy, East Nancy, and Pachuta Creek Fields. The amount of closure (relief) over these salt cored anticlines is considered to be a measure of the amount of upward movement of the salt mass.

#### Structural Framework

The present structural configuration of the study area is shown on the Structure Map of the Smackover Formation (Plate V). Structure maps were also prepared on the Louann Salt and the Norphlet Formation during the course of the study, but these are of less value because of the paucity of control points at the deeper horizons. The Smackover structure map was constructed using only geophysical well logs as seismic and gravity information were not available for this study.

The Structure Map illustrates the effects of the Louann substratum on the present configuration of the top of the Smackover Formation. In the northeast corner of the map, the large inferred fault "A" defines the updip limit of the

of the salt. Although this feature is mapped as a down-to-the-south normal fault, it could as easily be: (1) a steep basement flexure such as a south-facing monocline, or (2) an erosional scarp. The structural style on the north side of fault "A" is controlled by the pre-Louann basement, and steeper dip rates are expected. South of the fault, the dip rate of the top of the Smackover is less steep due to the thickening wedge of salt. Fault "B" which traverses the north flank of Pachuta Creek Field and the south flank of Harmony Field again separates the area according to style of deformation. Between Faults "A" and "B," the top of the Smackover Formation dips basinward at a rather uniform rate. Harmony Field which lies within this area is not considered to have been formed by underlying salt movement. Although salt probably underlies the structure, there is no closure at the top of the Smackover (producing horizon) and the reservoir is thought to be a stratigraphic trap. South of Fault "B," however, northeast-southwest trending salt-cored anticlines are superimposed upon the regional south-west dip. The style of deformation across the study area is probably controlled by the thickness of the underlying salt; between Faults "A" and "B," the salt is relatively thin and did not respond to overburden pressure, whereas south of Fault "B," the salt is thicker and therefore yielded to overburden pressure. The southernmost structure, the Goodwater Field, also illustrates this structural trend as it has the steepest dip rate and

probably a greater amount of structural closure.

### Depositional History

The rocks overlying the Louann Salt along the north flank of the Mississippi Salt Basin consist of terrigenous clastics, carbonates, and evaporites. These varied lithologies undoubtedly reflect the tectonic influences both in the borderlands and within the basin. In this section, the depositional history of each formation is summarized in terms of the larger tectonic influences, as well as penecontemporaneous salt movement and faulting. The regional stratigraphic cross-section (Plate VI) illustrates the stratigraphic variations of the Norphlet Formation, Smackover Formation, and the lower member of the Buckner Formation across the study area.

#### Lower Member, Norphlet Formation

No information is available on the stratigraphic relationships between the Louann Salt and the overlying Norphlet Formation. The black shale facies at the base of the Norphlet may represent the terminal phase of Louann deposition as the Louann sea withdrew. Because the facies appears to be laterally restricted (Figure 3), it is possible that the laminated black shale was deposited in a local East-West trending sink. The absence of sand or silt-sized detritus suggests an isolated basin, free from fluvial deposits.

The overlying red siltstone facies indicates an influx



of detritus into this part of the basin. Whether this influx followed a period of erosion of the underlying Louann Salt as suggested by some authors is indeterminant at this time. The red siltstone was probably deposited in an intertidal to supratidal environment along an arid shoreline. It appears possible that the red siltstone represents the shoreline facies of the regressive Louann Sea. In this manner, salt deposition probably continued in deeper parts of the basin as the red siltstones were deposited over the updip salt deposits. The detrital influx indicates a renewed period of erosion in the border land, and arid conditions persisted as evidenced by the pervasive hematitization and occurrence of anhydrite nodules in the red siltstone facies. During deposition of the Norphlet, the Central Mississippi High was probably emergent as the Norphlet clastics do not extend north of the "A" fault.

The isopach map of the lower member (Figure 3) illustrates a trend of differential subsidence that persisted until the end of Smackover deposition. Across Pachuta Creek and Harmony Fields and the area to the north, the Lower Norphlet is relatively thin. However, to the south the lower Norphlet thickens into a northwest-southeast trending trough. Farther to the south, the member appears to thin along a line from Goodwater Field to south of the Prairie Branch Field, but data is sparse in this area. There is no evidence of salt movement at this horizon, and the thickness variation is thought to reflect differential

subsidence, possibly controlled by basement faulting.

#### Upper Member, Norphlet Formation

The quartz sandstone facies of the upper member is thought to represent deposition along a low-lying desert coast, as the sequence includes both inferred eolian sands and intertidal sands. Although data is insufficient to permit reconstruction of the paleogeography, it appears that the coastline was situated in the southern part of the study area with coastal dune sands present to the north and shallow water intertidal sands to the south. Under this situation, minor changes in the rate of subsidence, rate of sediment influx, or prevailing wind direction would cause transgressions and regressions of the shoreline. During deposition of the upper Norphlet, it seems likely that hypersaline waters were present in the basin as the inferred intertidal sands are nonfossiliferous. Carbonate deposition (Smackover) possibly began at least during the terminal phase of Norphlet deposition, but it is doubtful that "normal marine" conditions existed as the basal Smackover beds are devoid of fossils. In East Nancy Field the quartz sandstone facies is overlain by laminated dolomite (with rare "birdseye" structures), and in Goodwater Field to the south the facies is overlain by nonlaminated dolomitic micrite. It is possible that the laminated dolomite was deposited in low areas controlled by the depositional topography of the underlying Norphlet sandstone as

deposition of the offshore facies (dolomitic micrite) occurred to the south in Goodwater Field.

The thickness variations of the Upper Norphlet are similar to that described for the Lower Norphlet. The influx of sand-sized detritus in the upper member appears to have been primarily from the East as the facies is not present in appreciable amounts in the western part of the area. As shown in Figure 5, the sandstone is absent over the Pachuta Creek and Harmony Fields, but is present between the fields and in the area to the north of the fields. South of the Pachuta Creek and Harmony structures, the sandstone thickens in the same manner as the Lower Norphlet with possible thinning along the southern boundary of the study area. It is doubtful that there was any movement within the salt mass (halokinesis) during deposition of the Norphlet Formation. The broad isopach features are more suggestive of differential subsidence probably originating in the pre-Louann basement. A possible exception to this is in the Goodwater Field where three data points are available which can be contoured to show thinning across the structure. However, with such few data points, it could not be determined if this represents an early movement of the underlying salt mass or depositional geometry of the sand bodies. The East-West trending trough in the southern part of the area appears to have persisted throughout Norphlet deposition, and may be related to tensional stresses set up along the hingeline due to more rapid

subsidence to the south.

#### Lower Member Smackover Formation

The lower member consists of carbonates with very little included silt or sand-sized detritus, indicating a subdued borderland. In Goodwater Field, the lower part of the member is thought to be the offshore facies equivalent of the Upper Norphlet shoreline sands and the overlying laminated dolomite facies (Plate VI). In the main body of the member, the core data indicates a series of alternating, very restricted intertidal and subtidal deposits. These facies are thought to represent deposition in a broad shallow water carbonate coastal plain in which carbonate sediment production kept pace with subsidence.

On the isopach map (Figure 8), the thickness variations are much greater than described for the Norphlet Formation, although this may be due in part to an increase in the number of data points. In the northern part of the area, the member is relatively thin over the Harmony Field, but thickens into the Pachuta Creek and East Nancy Field areas. In the southern area, the thickness variations are less uniform. In the only two areas for which sufficient data points are available (East Nancy and Goodwater Fields), the member appears to thicken across the structures. Consequently, thin areas are mapped on the northeast side of East Nancy Field and the southeast side of Goodwater Field. Because the pattern of thickening and thinning of the

Lower Smackover in the southern area is different from that described in the Norphlet Formation, there appears to be a change in the pattern of differential subsidence. This change, although based on few data points in the Norphlet Formation is probably evidence of early movement of the underlying salt. If these isopachous features do in fact indicate salt flowage, then the apex of the salt structures during deposition of the Lower Member was displaced from the present structural apex of the salt cored anticlines.

#### Upper Member, Smackover Formation

The upper member lithofacies represents the first evidence of widespread open marine conditions. The pelletoidal micrite facies at the base is inferred to be the deepest water deposits with subsequent shoal water deposits overlying the pelletoidal micrite beds. Contrasted with the lower member, the upper Smackover is a normal open marine deposit with a varied marine fauna. From the deeper water pelletoidal micrites, the vertical sequence indicates progressively shallower water deposits, from subtidal superficial oömicrites to intertidal oölites and superficial oölites and finally lagoonal dolomites. Along the line of section (Plate VI), the thick sequence of oolites and superficial oolites extend from the north flank of the Goodwater Field to Harmony Field. To the south in Goodwater Field, the oölites grade into the subtidal superficial

oomicrite and pelmicrite beds, and to the north of Harmony Field the oölite and superficial oölite beds grade into lagoonal dolomites and supratidal anhydrites.

The isopach map (Figure 14) indicates that during deposition of the upper member, movement of the underlying salt had established the present structural configuration of the salt cored anticlines. This is especially evident in the Goodwater and East Nancy Fields which are clearly outlined by thinning of the upper member across the structures. However, in the Pachuta Creek and Nancy Fields, thinning of the upper member is less evident, but this may be due to fewer control points. The area of thinning in the Harmony Field area is similar to the pattern described for the Norphlet Formation and lower member of the Smackover Formation. Therefore, this feature is thought to be a structural salient, probably developed in the pre-Louann basement independently of salt movement.

In the discussion of depositional environments of the oolite and superficial oolite facies, it was suggested that these deposits occur as a continuous linear body of sediment trending northwest-southeast across the study area. It was also suggested that the oölite shoals developed where a gradual rise of the sea floor created an area of high energy caused by coincidence of wave base and sloping sea bottom. Under these conditions, the oölites formed and further contributed to the development of the shoal topography by normal sedimentary processes. In the sheltered

area behind the shoal, the oncolitic superficial oölite facies was deposited. An alternate proposal would be that the oölite shoals were established over local bathymetric highs caused by upward movement of the salt cored anticlines. That salt movement did in fact affect the bottom topography of the sea floor is evident from the isopach map which shows thinning over the crest of the Goodwater and East Nancy Field structures. If this mechanism is responsible for the development of the shoals, then the oölite deposits would form isolated sedimentary bodies whose position in the basin was controlled by the location of the salt cored anticlines. It is difficult to evaluate the significance of salt structure control on the development of oölite shoals because most of the wells are drilled over the structures. In addition, as the isopach map includes all of the upper Smackover interval, it cannot be determined exactly what part of the interval is relatively thin. Attempts to isopach the oölite and superficial oölite intervals together (based on geophysical log data) were not definitive because the variation was so small that it could be explained easily as a normal sedimentologic variation. Apparently, the only definitive approach possible is to compare wells drilled on structure to those that are demonstrably off structure. Only two wells in the area are thought to have been drilled off structure, the Pruet #1 - Goodwin 9-5 (Sec. 9 IN-14E) which lies between the Nancy and West Nancy salt structures, and the Harris #1 Evans 4-4

(Sec. 4, 1N-15E) which lies between the East Nancy salt structure and the Harmony Field (Plate IV). The Pruet well appears to have a normal section of porosity based on geophysical log interpretation. In the case of the Harris well, drill cutting samples were examined and the section was found to be very similar to the East Nancy Field section. Further support for the idea that the oölite and superficial oölite beds are part of a continuous body of sediment lies in its relation to adjacent facies. The subtidal superficial oömicrite and pelmicrite facies which are inferred to have formed on the seaward flanks of the oölite shoal are interbedded with oölites only in the south in Goodwater and North Shubuta Fields. In Nancy and East Nancy Fields, the superficial oömicrite facies always underlies the oölite facies indicating that the oölites prograded over the superficial oömicrite beds. It is therefore concluded that the oölite and oncolitic superficial oölite rocks were deposited as a continuous band of high energy shoals whose location was generally controlled by the regional topography of the basin. The idea that salt structures may control the location of oölite shoals would appear to be more reasonable to the south of the study area away from the more stable hingeline area.

#### Lower Member, Buckner Formation

The lowermost part of the lower Buckner represents the supratidal equivalent of the Smackover Formation. The



supratidal area consisted of broad flat coastal sabkhas which formed above the Smackover strandline and upon which was accumulated thick deposits of nodular anhydrites and interbedded dolomites. The interbedded dolomites are thought to be the deposits of small brackish lakes which developed within the coastal sabkhas. The basinward progradation of these supratidal environments over the regressive Smackover beds resulted in a thick sequence of evaporites and dolomites which extend continuously along the north flank of the Mississippi Salt Basin from southern Alabama through central Mississippi.

Faulting appears to have been initiated during deposition of the lower member of the Buckner Formation. The fault pattern shown on the Smackover Structure Map (Plate V) was constructed primarily from thickening and thinning within the lower member (Plate IV). In the only two areas in which wells are cut by faults (the north flank of Pachuta Creek Field and the North Shubuta Field), the downthrown Lower Buckner section is unusually thick. All of the faults (B-E) are considered to have been active during deposition of the lower Buckner with thickening into the faults.

The salt cored structures, Pachuta Creek, Nancy, East Nancy, and Goodwater Fields all reflect salt movement during Buckner Deposition (Plate IV). The pattern of salt anticline growth established in the Upper Smackover is therefore continued into the Lower Buckner. Because of the greater number of isopach values in the Lower Buckner, structural

growth is more clearly defined by thinning over the crest of the structures and thickening along the flanks. However, it should be noted that thickening of the member is more pronounced on the north flank than on the south flank of these structures. This may be due either to northward thickening into the faults which are thought to traverse the north flank of the fields, or to a post-Buckner northward shift of the structural apex caused by a southward tilting. When the amount of structural growth of the salt features during deposition of the upper member is considered, it is evident that the salt structures had their maximum upward movement during the Buckner interval. After this period, the salt structures remained essentially static, as there is little evidence of subsequent movement.

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APPENDIX A  
METHODS OF PETROGRAPHIC ANALYSIS

A1. Procedures

Thin sections made from conventional cores provide the basic data for this study. Approximately 100 thin sections were made from cores of the Norphlet Formation, 400 thin sections from the Smackover Formation, and approximately 50 thin sections were made from the lower member of the Buckner Formation. Petrographic thin sections were also made from drill cuttings of which 250 were utilized from the Norphlet Formation and 100 from the upper member of the Smackover Formation.

Mineral identification was accomplished by microscopic analysis, chemical staining, and to a lesser extent by X-ray diffraction analysis. All of the thin sections were stained with a mixture of alizarin red S and potassium ferricyanide to differentiate the various carbonate minerals and their iron content. X-ray patterns were run on selected bulk samples as a check on mineral identification.

For compositional and textural analysis, only visual estimates were made in this study. Because of the large number of thin sections examined, conventional point count methods were not considerable feasible. Percentage estimates

of composition were made by using the visual measurement chart by R. L. Folk (1951), and values for roundness and sorting were determined by image comparison with charts published in Folk (1968). Grainsize estimates were made by visually scanning the thin section and selecting the most frequently occurring size which was measured using an ocular micrometer. The Wentworth grain-size scale was used for the description of the terrigenous clastic rocks, and the Folk grain-size scale was used for the carbonate rocks (Folk, 1962).

APPENDIX A  
METHODS OF PETROGRAPHIC ANALYSIS  
A2. Classification of Sandstones

In this paper, Pettijohn's classification (1957, p. 290-293) of sand-sized terrigenous clastics is used. Under this scheme, the relative abundance of quartz plus chert, feldspar, rock fragments, and detrital matrix are used as the basis for classification. The sandstone classification was used only to describe the rocks of the upper member of the Norphlet Formation. In the uppermost part of the Smackover Formation, carbonate allochems and terrigenous clastics are frequently mixed in various proportions. In these rocks, the dominant terrigenous grain is always quartz and the interstitial material is nearly always dolomite. When the depositional texture is packed or grain supported, and the volumetric percentage of terrigenous grains is greater than allochemical grains, the rock is referred to as dolomitic quartz sandstone. In the case where the percentage of allochemical grain is greater than terrigenous grains, the carbonate classification is used to describe the rock.

APPENDIX A  
METHODS OF PETROGRAPHIC ANALYSIS  
A3. Classification of Carbonates

Petrographic description of the carbonate rocks essentially follows the classification of Folk (1962, 1965). However, some modification was necessary to accommodate the particular types of allochems found in the Smackover Formation. Figure 28 is a summary chart of the classification of carbonate rocks used in this study which is modified from Folk's chart. The essential differences are an addition of two columns to the volumetric Allochem Composition (oncolites and superficial oölites) and subdivision of the Replacement Dolomite column. Implicit in the manner in which Folk's chart is modified for this study is the opinion that for environmental interpretation, oölites are more significant than oncolites, oncolites are more significant than superficial oölites, and superficial oölites are more significant than pellets or fossils. In the following discussion, the terms and conventions used in the petrographic description of the carbonate rocks are defined.

The terminology of diagenetic calcite is used in the same sense as Folk, 1965: Micrite refers to microcrystalline calcite, 0.001 - 0.00+mm in size; microspar is used for

Limestones and Partly Dolomitized Limestones							Replacement Dolomites				

\* Replacement Dolomites Subdivided into Three Columns  
 \*\* Addition of Oncolite and Superficial Oolite Columns

FIGURE 28. Classification of Carbonate Rocks (Modified from Folk, 1962)

neomorphic calcite, 0.005-0.030mm in size; and pseudospar for neomorphic calcite, 0.030mm in size. The term sparry calcite refers to directly precipitated calcite cement. However, in the Smackover rocks, chemically precipitated sparry dolomite was found to be as common as sparry calcite. For this reason, the terms calcspar and dolospar are used to designate sparry calcite cement and sparry dolomite cement, respectively (Bissell and Chilingar, 1967). In the rock names (Figure 28), dolospar is used as the suffix when the dominant cement is sparry dolomite; for example, oödolospar refers to an oölite rock which is cemented by dolospar. Chemically precipitated carbonate cements are also classified in this study according to crystal morphology and five types were identified: bladed calcite crusts, syntaxial rim cement, euhedral dolospar, blocky dolospar, and blocky calcspar. These various kinds of void-filling cement are described in the section Cementation in Offshore Oölite and Superficial Oölite Facies. Commonly calcspar and dolospar are both present as cements in which case the dominant mineral is used for the rock name and the subordinate cement type is used as a modifier; for example, calcitic oodolospar refers to oolites cemented with greater than 50 percent dolospar and less than 50 percent calcspar. The amount of total interstitial cement was found to be highly variable and the rocks range from well cemented to poorly cemented. To emphasize this feature, the prefix "porous" is used where less than 50 percent of the total



interstitial space is filled with cement or matrix.

Replacement dolomites are very common in the Smackover and Buckner Formations and occur both as interstitial dolomite (between calcite allochems) and as dolomite "matrix" in predominantly dolomite rocks in which allochems are a minor constituent. Dolomite replacing allochems was found to be very rare in the carbonate section. In order to emphasize in a general way the relative amount of allochems present in the dolomite rock, the following modification of Folk's chart is used:  $> 10\%$  allochems (i.e. oölites) = oölitic dolomite; 1-10% allochems = oölite-bearing dolomite; and  $< 1\%$  allochem = dolomite (See Figure 28). The size convention of the dolomite crystals is the same as in Folk, 1962; aphanocrystalline =  $< 0.004\text{mm}$ , very finely crystalline =  $0.004\text{-}0.016\text{mm}$ , finely crystalline =  $0.016\text{-}0.062\text{mm}$ , and medium crystalline =  $0.062\text{-}0.250\text{mm}$ . For a discussion of the criteria used to distinguish replacement dolomite from sparry dolomite cement, the reader is referred to the section "Dolomitization of Oolite-Quartz Dolomite Facies," Page 92 .

## APPENDIX A

### METHODS OF PETROGRAPHIC ANALYSIS

#### A4. Description of Allochems and Fossils

The allochems found in the Smackover Formation are primarily accretionary grains and in order of abundance these are oolites, superficial oolites, and oncolites. However, pellets, fossils, and intraclasts are found in significant amounts in some lithofacies. Because the allochems are critical to the analysis of depositional environments, a description of each type is included here.

#### Oölites

Oölites consist of carbonate grains which are spherical to subspherical and range in size from 0.150mm to as large as 3mm. The most frequently occurring size is in the medium to coarse calcarenite range (0.250 to 1mm). The oölites are characterized by a series of concentric layers of oriented calcite crystals about a nucleus (Newell, Purdy, and Imbrie, 1960), the thickness of the coating being generally greater than the radius of the nucleus. Micrite material, probably pellets, are the most common nuclei for the oölites although detrital quartz nuclei were found to be locally abundant.

### Pellets

Pellets are small (less than 0.150mm in diameter), spherical in shape, and composed of micrite material showing no significant internal structure (Folk, 1962). Variation in size of the pellets is considerable throughout the Smackover Formation although certain sizes appear to be dominant in some lithofacies. The two most prominent size ranges are: 0.030 to 0.060mm and 0.070 to 0.120mm.

### Superficial Oölites

The term superficial oolite is used to describe spherical to subspherical grains which have a thin external oolitic coating. As defined by Bissell and Chilingar, 1967, it is a type of oölite in which the thickness of the accretionary coating is less than the radius of the nucleus. The superficial oölites consist of one or more concentric layers of oriented calcite crystals around a pellet nucleus (Figure 19D). These appear to be similar to the oölitic films on "peloids" described by Bathurst (1967) from Bimini Lagoon, Bahamas.

### Oncolites

Oncolites consist of spherical to irregularly coated grains which exhibit considerable variation in size, shape, and internal structure. Oncolites are considered to result from sediment trapping by blue-green algae which encrust freelying grains (Pia, 1927; Logan, et al., 1964). Two

distinct varieties are present in the Smackover Formation, dense oncolites and spongy oncolites, each of which is strongly facies controlled.

Dense oncolites (Figure 19C) are spherical shaped accretionary grains consisting of thick concentric layers of micrite-size calcite around a nucleus (Type SS, Mode C of Logan, et al.). Where preservation is good, the micrite appears unoriented and is easily distinguished from oolitic coating. Intraclasts, oolites, and fossils are the most common nuclei although in many cases, a distinct nucleus could not be defined. Thickness of algal laminations is highly variable and for classification purposes, oncolite is used where the thickness of the coating is greater than the radius of the nucleus; and micrite coated grain is used where the coating is less than the radius of the nucleus. The dense oncolites are large and typically range in size from 1 to 4mm in diameter.

Spongy oncolites (Figure 10F, 16D) refer to large spherical, poorly organized grains which consist of micrite laminae alternating with thicker layers of entrapped grains, usually pellets. Contrasted with the dense oncolites, these appear structurally weak with many open spaces between the loosely packed pellets. Distinct nuclei are usually lacking and the overall texture has a spongy appearance. These oncolites are associated with micrites and pelmicrites and along the grain edges appear to merge into the country rock without a distinct boundary. In size, the spongy oncolites range from

0.1mm to several centimeters in diameter, but because of the poor organization of the structure it is difficult to distinguish between whole forms and fragments. These oncolites commonly show some degree of diagenetic alternation either by chertification or dolomitization.

### Intraclasts and Composite Grains

Intraclast is used to describe irregular fragments of calcite or dolomite, generally greater than 0.2mm (Folk, 1962). Only two types of intraclast were found in significant amounts: lumps or masses of microcrystalline carbonate material which frequently show bedding features, and a "botryoidal" type intraclast (Illing, 1954) in which several pellets or small oolites are enveloped by oolitic or oncolitic laminae. The former is referred to as intraclasts and the latter as composite grains in order to distinguish the two varieties in this study.

### Fossils

Organic remains are essentially restricted to the upper member of the Smackover Formation and rarely constitute more than ten percent of the grains. No fossils were found in the Norphlet Formation, and in the lower members of the Smackover and Buckner Formations, only rare occurrences were noted. The fossils are usually broken and are almost always heavily coated with micrite. The coating is probably algal in origin as a complete transition sequence

is evident between coated fossils and oncolites with fossil nuclei.

No attempt was made to systematically define the fossil assemblage although the fossils were routinely recorded in the petrographic description, and the more obvious forms were identified on the basis of shell microstructure and morphology. The more common fossils, in order of abundance are: bivalves, echinoderms, gastropods, algae, corals, and brachiopods. These are briefly described below and their distribution is discussed later under the sections on petrology.

### Bivalves

Two types of bivalves are common: large, well preserved shell fragments of ostreidae and smaller, more numerous undifferentiated fragments which are poorly preserved and frequently recrystallized. The latter were identified as bivalves on the basis of shell morphology and distinguished from brachiopods by the lack of preservation.

### Echinoderms

Echinoderm fragments, spines, and plates are prominent and easily identified by their single crystal structure and reticulate texture. Snytaxial overgrowths on echnoid fragments are rare because the algal coating appears to retard crystal overgrowth.

### Gastropods

High spired gastropods are completely recrystallized to a calcite mosiac and the wall structure is never preserved. These were identified by shell morphology and are frequently found forming the nucleus of oncolites.

### Calcareous Algae

Both red algae and calcareous green algae are relatively abundant in the upper member of the Smackover Formation. The red algae are represented by solenoporaceae which usually form small nodular masses. In thin section, the solenoporaceae appear as long radiating cells separated by transverse poorly defined partitions. Other algae, tentatively identified as belonging to the family Codiaceae (green algae) are poorly preserved and are present as thin plates in which the structure is completely recrystallized. In isolated specimens, features suggestive of cells arranged perpendicular to the walls were noted, but the principle criteria for identification is the plate-like shape and irregular surface. Another type, although minor, has a spherical shape and consists of irregularly spaced tubes with microcrystalline carbonate material separating the tubes. This form was also tentatively identified as codiacean algae.

### Corals

The corals occur as free-lying fragments and are

exclusively colonial. Only the peripheral edge of the coral is preserved and the central mass is completely recrystallized to a calcite mosaic. In some of the larger fragments, the central mass is replaced by anhydrite. In rare occurrences where the coralites are preserved, a six-fold symmetry of septa is evident and the corals are considered to be scleractinian corals.

### Brachiopods

Two kinds of brachiopods were identified: a small well preserved thin-shell form with punctate wall structure, identified as terabratulids, and a larger unidentified form which has an impunctate shell. The latter form was identified as a brachiopod on the basis of the fine, inclined prismatic microstructure (Majewski, 1969).



APPENDIX A

METHODS OF PETROGRAPHIC ANALYSIS

A5. Description and Origin of Anhydrite

Anhydrite is a common constituent throughout the Smackover and Buckner Formations, and to a lesser extent in the Norphlet Formation. Individual anhydrite crystals occur in a variety of fabrics, the three most significant being: 1) lenticular anhydrite, 2) elongated anhydrite laths, and 3) felty anhydrite crystals in polycrystalline nodules. The lenticular anhydrite and felty anhydrite fabrics are thought to be formed under conditions which were controlled by the initial depositional environment (early diagenetic), whereas the lath-shaped anhydrite is thought to be formed during a later stage of diagenesis.

Lenticular Anhydrite

This variety of anhydrite is lens-shaped and usually occurs as small single crystals, 0.5 to 1.0mm in length (Figure 11E). In cross-section, the anhydrite crystals have a characteristic "spindle" shape with no preferred orientation relative to bedding. The crystals are generally devoid of inclusions, and commonly appear as clear crystals with sharp smooth boundaries. Lenticular anhydrite is

essentially restricted to the laminated micrite facies of the lower member of the Smackover Formation and only rare possible occurrences of lenticular anhydrite were noted elsewhere in the section. The distribution of lenticular anhydrite in the laminated micrite is variable with some zones having a higher concentration than others. However within any one zone, the crystals are uniformly spaced and do not appear to form distinct clusters of crystals.

The lenticular anhydrite in the Smackover Formation is thought to be anhydrite pseudomorphic after gypsum. The lens-shaped habit is typical of primary gypsum, and lenticular gypsum has been reported from modern intertidal and supratidal environments by numerous authors (Masson, 1955; Kinsman, 1969; Davies, 1970). In the intertidal and supratidal environments, evaporation of surface waters causes interstitial pore-fluid concentration and direct precipitation of evaporite minerals. According to Kinsman, 1969, the "lensoid" gypsum crystals are precipitated within the host sediments and are emplaced by physical displacement of the host grains. In ancient rocks, crystal habits variously described as "bladed" (Kerr and Thompson, 1963), "lens-shaped" (West, 1964), and "lenticular" (Carozzi and Textoris, 1967) have been inferred to be pseudomorphic after primary gypsum. This interpretation appears to be reasonable as the lenticular shape is described as one of the common shapes of primary gypsum (Dana's Textbook of Mineralogy, 4th edition, 1966) which crystalizes in the

monoclinic system. By contrast, anhydrite which crystallizes in the orthorhombic system has a rectangular shape, without curved crystal faces. It should be noted that in the case of the Smackover lenticular anhydrite, it could not be definitely established whether the anhydrite directly "replaced" gypsum, or that the primary gypsum was dissolved leaving lenticular molds which were later filled by anhydrite.

#### Elongated Anhydrite Laths

This variety of anhydrite has an elongated lath-like habit (Figure 21F) with crystal faces which are parallel to well developed rectangular cleavage planes. The anhydrite laths are typically larger than the lenticular anhydrite, and frequently measure several millimeters in length. Also, the anhydrite laths rarely occur as single crystals and the usual form is a random, parallel, or radiating cluster of crystals. Commonly, the crystals contain inclusions (poikiloblastic) of dolomite and other host-rock impurities. Unlike the other varieties of anhydrite (lenticular and felty nodules), the lath-shaped anhydrite does not appear to be closely related to specific lithofacies units and occurs throughout much of the Smackover and Buckner sections.

The lath-shaped anhydrite is thought to be a primary mineral, that is, not derived by replacement of a pre-existing gypsum crystal. Two modes of origin are evident:

1) anhydrite laths replacing calcite, and 2) anhydrite laths precipitated in open spaces. However, where the anhydrite crystals are free of inclusions, the exact mode of origin is frequently indeterminant. The replacement anhydrite apparently replaces only calcite because in rocks with both calcite and dolomite, the calcite can be seen in various stages of being replaced whereas the dolomite is unaffected. As a result of this preferential replacement, dolomite inclusions are typical of the anhydrite laths (poikiloblastic). Where the anhydrite has replaced calcite that is relatively free of impurities (such as calcspar cement), the resulting crystals cannot be distinguished from pore filling anhydrite cement. Similarly where anhydrite laths occupy a former allochem site that is enclosed in a dolomite matrix, it cannot be determined with certainty if the allochem was replaced by anhydrite or that the allochem was first dissolved and the resulting mold was later filled with precipitated anhydrite. With both replacement anhydrite and precipitated anhydrite, it is probable that the occurrence of lath-shaped anhydrite was not related to conditions at the time of deposition of the host-rock material, but rather was formed during a later diagenetic stage.

#### Felty Anhydrite in Polycrystalline Nodules

Small irregular lamellae of anhydrite which are intergrown into a felted network of crystals has come to be

known as felty anhydrite (Carozzi, 1960). Individual crystals are rarely greater than 0.2mm in length, and have a length to width ratio of approximately five to one. The felty crystals occur as crystal aggregates which are organized into roughly spherical nodules ("Marocells" of West, 1965). The crystals show a tendency toward parallelism of the long axis and frequently occur as swirls of sub-parallel crystals near the center of the nodule. Near the outer boundary, the crystals are uniformly oriented with the long axis parallel to the outer surface. Larger crystals probably representing recrystallized anhydrite are occasionally present and these usually contain relic texture of the smaller felty crystals. The anhydrite nodules are noticeably free of any impurities such as dolomite or detrital grains.

The nodules are of irregular tuberous shape and range from 1mm to several cm in size. They may occur closely packed forming an anhydrite mosaic (Figure 26A), or as sparse nodules "floating" in a carbonate matrix. In the anhydrite mosaics, the boundaries between nodules are outlined by darker seams of interstitial material, usually dolomite. Where the host-rock is stratified, the bedding planes are deflected by the nodule, indicating that the nodule grew by accretion in soft sediment and mechanically displaced the primary sediment.

The felty anhydrite nodules occur in the Norphlet, Smackover, and Buckner Formations. In the Buckner

Formation, the anhydrites are a major constituent where they occur in a matrix of aphanocrystalline to very finely crystalline dolomite. In the upper member of the Smackover Formation, small beds of nodular anhydrite in dolomite are occasionally interbedded with oolite rocks. In the Norphlet Formation, a few scattered small nodules were found embedded in red mudstones, siltstones, and sandstones.

The anhydrite nodules are thought to be formed under supratidal conditions, by evaporative concentration of pore fluids. The nodules appear to have grown by accretion in soft sediment near the sediment/air interface under conditions similar to those forming today in the Trucial Coast (Shearman, 1966; Kinsman, 1969). Evidence for this interpretation is cited in the section "Depositional Environments of the Lower Member of the Buckner Formation." In the recent literature, controversy has focused on the question of whether the anhydrite is primary or formed as a replacement of primary gypsum. Holliday (1968) working on the Spitsbergen deposits suggested that the lath-shaped anhydrite crystals in nodular anhydrite represents primary anhydrite. West (see discussion of Holliday's article in Holliday, 1968) expressed the opposing view that the anhydrite laths are a replacement of primary gypsum based on evidence from the Purbeck Beds in Sussex. No new information is offered on the problem of diagenesis of the felty anhydrite nodules in this study. However, by visual comparison with published photomicrographs, the felty anhydrite

nodules of the Buckner and Smackover Formations appear to be more like the epigenetic felty anhydrite of Carozzi (1960), and least like the "lath-shaped" anhydrite nodules of Holliday, 1968. Regardless of the explicit diagenetic history of the felty anhydrite (primary vs. secondary), it is evident that the nodules formed in soft sediment prior to lithification and are therefore important to the analysis of paleodepositional environments.

## APPENDIX B

### LITHOFACIES - WELL CONTROL

#### B1 Norphlet Formation, Lower Member

##### Black Shale Facies

#### Drill Cuttings

Chevron #1 - Hand (Watts Creek)

Getty #1 - Masonite 17-13 (E. Nancy)

Getty #1 - Masonite 14-4 (Nancy)

Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

##### Red Siltstone Facies

#### Conventional Cores

Shell #1 - Johnston (Goodwater)

#### Drill Cuttings

Shell #1 - Johnston (Goodwater)

Shell #1 - Ulmer (Goodwater)

Getty #1 - Masonite 17-13 (East Nancy)

Getty #1 - Masonite 14-4 (Nancy)

Exchange #1 - Evans 35-1 (North Shubuta)

Chevron #1 - Hand (Watts Creek)

Getty #1 - Creek (Pachuta Creek)

Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)

Harris #1 - Moore 10-12 (WC/Sec. 10, 3N-14E)



## APPENDIX B

### LITHOFACIES - WELL CONTROL

#### B2 Norphlet Formation, Upper Member

##### Quartz Sandstone Facies

#### Conventional Cores

Shell #1 - Johnston (Goodwater)  
Exchange #1 - Evans 35-1 (North Shubuta)  
Chevron #1 - Hand (Watts Creek)  
Getty #1 - Masonite 18-8 (East Nancy)  
Getty #1 - Allen 20-7 (East Nancy)

#### Drill Cuttings

Shell #1 - Johnston (Goodwater)  
Shell #1 - Ulmer (Goodwater)  
Getty #1 - Masonite 17-13 (East Nancy)  
Getty #1 - Masonite 14-4 (Nancy)  
Exchange #1 - Evans 35-1 (North Shubuta)  
Chevron #1 - Hand (Watts Creek)  
Getty #1 - Creek (Pachuta Creek Field)  
Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)  
Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)  
Harris #1 - Moore 10-12 (WC/Sec. 10, 3N-14E)

## APPENDIX B

### LITHOFACIES - WELL CONTROL

#### B3 Smackover Formation, Lower Member

##### Laminated Dolomite Facies

#### Conventional Cores

Getty #1 - Allen 20-7 (East Nancy)

Getty #1 - Masonite 18-8 (East Nancy)

#### Drill Cuttings

Getty #1 - Masonite 17-13 (East Nancy)

Getty #1 - Masonite 14-4 (Nancy)

Chevron #1 - Hand (Watts Creek)

Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)

##### Mottled Dolomite Facies

#### Conventional Cores

Getty #1 - R. Williams 18-9 (East Nancy)

Getty #1 - Collins Coleman 18-15 (East Nancy)

Getty #1 - Allen 20-3 (East Nancy)

#### Drill Cuttings

Not identified in drill cuttings

### Laminated Micrite Facies

#### Conventional Cores

Shell #1 - Johnston (Goodwater)  
Getty #1 - R. Williams 18-9 (East Nancy)  
Getty #1 - Collins - Coleman 19-1 (East Nancy)  
Getty #1 - Allen 20-3 (East Nancy)  
Chevron #1 - Hand "2" (Watts Creek)

#### Drill Cuttings

Not identified in drill cuttings

### Fossiliferous Micrite Facies

#### Conventional Cores

Getty #1 - R. Williams 18-9 (East Nancy)

#### Drill Cuttings

Not identified in drill cuttings

### Oncolitic Pellet Facies

#### Conventional Cores

Getty #1 - Allen 20-3 (East Nancy)

#### Drill Cuttings

Not identified in drill cuttings

## APPENDIX B

### LITHOFACIES - WELL CONTROL

#### B4 Smackover Formation, Upper Member

##### Pelletoidal Micrite Facies

#### Drill Cuttings

Shell #1 - Johnston (Goodwater)  
Shell #1 - Ulmer (Goodwater)  
Shell #2 - Johnston (Goodwater)  
Shell #1 - Masonite (Goodwater)  
Shell #1 - McCarty (Goodwater)  
Getty #1 - Masonite 17-13 (East Nancy)  
Getty #1 - Masonite 14-4 (Nancy)  
Exchange #1 - Evans 35-1 (Nancy)  
Chevron #1 - Hand "2" (Watts Creek)  
Harris #1 - Evans 4-4 (WC/Sec. 4, 1N 1-15E)  
Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)  
Harris #1 - Moore 10-12 (WC/Sec. 10, 3N-14E)

##### Superficial Oomicrite Facies

#### Conventional Cores

Shell #1 - Thomas (Goodwater)

#### Drill Cuttings

Shell #1 - Johnston (Goodwater)  
Shell #2 - Johnston (Goodwater)  
Shell #1 - Masonite (Goodwater)

Shell #1 - Ulmer (Goodwater)  
 Shell #1 - Ruter (Goodwater)  
 Shell #1 - McCarty (Goodwater)  
 Getty #1 - Masonite 17-13 (East Nancy)  
 Getty #1 - Masonite 14-4 (Nancy)  
 Chevron #1 - Hand "2" (Watts Creek)  
 Exchange #1 - Evans 35-1 (North Shubuta)  
 Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

#### Pelmicrite Facies

##### Conventional Cores

Shell #1 - Johnston (Goodwater)  
 Shell #1 - Thomas (Goodwater)

##### Drill Cuttings

Shell #1 - Johnston (Goodwater)  
 Shell #2 - Johnston  
 Shell #3 - Johnston  
 Shell #1 - Masonite  
 Shell #1 - Ulmer  
 Shell #1 - Ruter  
 Shell #1 - McCarty

#### Oölite Facies (Goodwater Field)

##### Conventional Cores

Shell #1 - Ruter  
 Shell #1 - Ulmer

Shell #1 - Johnston

Drill Cuttings

Shell #1 - Johnston

Shell #2 - Johnston

Shell #1 - Masonite

Shell #2 - Masonite

Shell #1 - Ulmer

Shell #2 - Ulmer

Shell #2 - Thomas

Shell #3 - Thomas

Oölite Facies (East Nancy Field)

Conventional Cores

Getty #1 - Coleman 18-15

Betty #1 - Masonite 18-8

Getty #1 - Masonite 17-13

Getty #1 - Allen 20-4

Getty #1 - Allen 20-7

Getty #1 - Masonite 20-10

Drill Cuttings

Getty #1 Masonite 17-13

Oölite Facies (Harmony Field)

Conventional Cores

Dunbar #1 - M. A. Kirkland 29-1

Masonite #1 - Kirkland 20-6

Mosbacher #1 - Board of Supervisors 16-13

Oölite Facies (Nancy Field)

Conventional Cores

Getty #1 - Masonite 14-4

Drill Cuttings

Getty #1 - Masonite 14-4

Oölite Facies (Pachuta Creek Field)

Conventional Cores

Shell #1 - Evans 26-6

Oölite Facies (Wildcat Wells)

Conventional Cores

Exchange #1 - Evans 35-1

Drill Cuttings

Harris #1 - Evans 4-4

Oncolitic Superficial Oolite Facies

Conventional Cores

Getty #1 - Coleman 18-15 (East Nancy)

Getty #1 - Masonite 18-18 (East Nancy)

Getty #1 - Masonite 17-13 (East Nancy)

Getty #1 - Allen 20-7 (East Nancy)

Getty #1 - Allen 20-10 (East Nancy)

Shell #1 - Evans 26-6 (Pachuta Creek)

Mosbacher #1 - Board of Supervisors 16-13 (Harmony)

### Drill Cuttings

Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

Getty #1 - Masonite 14-4 (Nancy)

### Oilite-Quartz Dolomite Facies

### Conventional Cores

Getty #1 Coleman 18-15 (East Nancy)

Getty #1 - Masonite 18-8 (East Nancy)

Getty #1 - Masonite 17-13 (East Nancy)

Getty #1 - Allen 20-4 (East Nancy)

Getty #1 - Allen 20-7 (East Nancy)

Getty #1 - Masonite 17-13 (East Nancy)

Getty #1 - Masonite 14-4 (Nancy)

Dunbar #1-A - Masonite 29-1 (Harmony)

Masonite #1 - Kirkland 20-6 (Harmony)

Mosbacher #1 - Board of Supervisors 16-13 (Harmony)

Harris #1 - Moore 10-12 (WC/Sec. 10 3N-14E)

### Drill Cuttings

Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)

Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)



APPENDIX B  
LITHOFACIES - WELL CONTROL  
B5 Buckner Formation, Lower Member

Conventional Cores

Shell #1 - Johnston (Goodwater)  
Getty #1 - Masonite 14-4 (Nancy)  
Getty #1 - Coleman 18-15 (East Nancy)  
Dunbar #1-A - M. Kirkland (Harmony)  
Mosbacher #1 - Board of Supervisors 16-13 (Harmony)

Drill Cuttings

Shell #1 - Johnston (Goodwater)  
Getty #1 - Masonite 14-4 (Nancy)  
Getty #1 - Masonite 17-13 (East Nancy)  
Harris #1 - Evans 4-4 (WC/Sec. 4, 1N-15E)  
Exchange #1 - Bufkin 6-7 (WC/Sec. 6, 2N-15E)  
Harris #1 - Moore 10-12 (WC/Sec. 10, 3N-14E)

APPENDIX C  
DETAILED PETROLOGY OF QUARTZ SANDSTONE FACIES,  
NORPHLET FORMATION

Quartz is the most abundant grain type and consists principally of quartz crystals with nonundulatory extinction. The grains are roughly equant in shape and range in size from fine to medium sand. Grain boundaries at points of contact usually show only slight penetration, and consequently the grains are rather loosely packed. Chert grains of the micro-crystalline quartz variety are always present to some degree and are typically better rounded than the associated quartz grains.

The next most abundant grain type is feldspar and includes both potassium feldspar and plagioclase feldspar. Many of the feldspar crystals are highly altered, but others appear fresh and commonly exhibit overgrowths of cement in optical continuity with the detrital grain. The highly altered grains are deformed and in some cases they are difficult to distinguish from detrital matrix material.

Detrital dolomite (Figure 4D) is present throughout the Upper Member and occasionally make up as much as ten percent of the grain content. The dolomite occurs as large single crystals and less commonly as polycrystalline aggregates. The single crystals are frequently zoned, but it is usually difficult to determine if the zoning is inherited or represents an authigenic overgrowth.

Rock fragments seldom account for more than ten percent of the grain content of the sandstones and are the least abundant of the major grain types. These are usually composed of finely crystalline micaceous material which is similar to some of the phyllitic shale fragments observed at the bottom of the Sun #1 Board of Supervisors (WC/Sec. 16, 3N-15E). These rock fragments may represent low grade metamorphic fragments eroded from the adjacent highland.

The most common types of accessory minerals are micas and opaques. The micas are essentially restricted to the red sandstone subfacies where they occur as relatively large crystals (0.100 - 0.150mm) oriented parallel to bedding. The opaque minerals are found throughout the sequence and are always more rounded than the associated quartz. In incident light, some of the opaque grains appear to be altered to hematite (probable magnetite) and others appear to be altered to leucoxene (probable ilmenite).

#### Matrix

The matrix material of the grey sandstone consists of sericite, probable clay minerals, minute quartz grains, and possibly feldspar grains. The present composition of the matrix is thought to be the result of diagenetic alterations of an original silt-clay detritus and is herein referred to as detrital matrix. In the red sandstone, the origin of the hematitic interstitial material is more problematic. The matrix appears to consist of hematite, sericite, very small

dolomite crystals, and possibly clay minerals. As T. B. Walker (1967) has pointed out, hematite is possibly a diagenetic alteration product of Fe-bearing minerals including both framework grains and detrital matrix. In the red sandstone subfacies, hematite alteration typically precludes any distinction between rock fragments, opaque grains, and detrital matrix. Also primary hematite cement in the form of translucent or opaque minerals would also be difficult to distinguish from the hematite alteration products.

### Cement

Cements are relatively rare in the Upper Norphlet beds and only small amounts of hematite, anhydrite, and dolomite were noted. The interstitial hematite in the red sandstone subfacies may represent either a primary precipitate or a replacement product. It occurs as stain coating both framework grains and detrital matrix, but may also be present as void-filling cement. Anhydrite cement occurs throughout the sequence, but is most abundant at the top of the upper unit (Figure 4E). The crystals are large and appear to show a preference for growing from one side of the interstitial void, as each void space is usually filled by a single crystal. Anhydrite crystals are not equally distributed throughout a thin section but occur as local patches of cement each consisting of several crystals. Dolomite is less common and occurs as overgrowths in optical continuity with the detrital dolomite nucleus and as small bladed crystals sparsely

decimated throughout the thin section.

Hartman (1968) reported halite cement from the Norphlet Formation in Pelahatchie Field, Rankin County, Mississippi. In an effort to detect halite cement, several thin sections were made using oil instead of water in the preparation process. Although none was observed, it is recognized that halite could possibly be dissolved in the coring process because of the high porosity and permeability of these rocks.

# APPENDIX D

## ISOPACH VALUES

\* NC - no correlation  
 NR - not reached  
 Fault - probable  
           faulted section

<u>Field/Well Name</u>	<u>Norphlet</u>		<u>Smackover</u>	
	<u>Lower</u>	<u>Upper</u>	<u>Lower</u>	<u>Upper</u>
<u>Goodwater Field</u>				
Shell #1 McCarty	NR	+100	560	400
Shell #1 Johnston	64	75	545	420
Shell #2 Johnston	NR	NR	537	372
Shell #1 Thomas	NR	+200	593	347
Shell #1 Ulmer	NR	NR	403	448
<u>East Nancy Field</u>				
Getty #1-Masonite 17-13	125	285	374	404
Getty #1-Harper 17-5	NR	NR	303	426
Getty #1-Masonite 17-12	NR	NR	369	410
Getty #1-Allen 17-14	NR	NR	357	445
Getty #1-Masonite 18-8	NR	NR	362	442
Getty #1-Allen 20-3	NR	NR	405	388
Getty #1-Allen 20-7	NR	NR	370	430
Getty #1-Masonite 20-10	NR	NR	393	389
Getty #1-C.Coleman 19-1	NR	NR	391Est.	454
<u>Nancy Field</u>				
Justiss-Mears #1-Masonite 11-8	NR	NR	466	479
Placid #1-Arledge 11-10	NR	NR	477	436
Getty #1-Masonite 14-4	86	320	463	483
<u>Prairie Branch Field</u>				
Pan Am #C-1 Masonite	60	30	450	412
<u>Watts Creek Field</u>				
Chevron #1-McCoy	NR	+160	224	676
Chevron #1-Hand	160	340	273	Fault?
<u>North Shubuta Field</u>				
Harris #1 Blair 34-1	130	Fault	Fault	Fault
Exchange #1-Evans 35-1	180	260	315	356
<u>Harmony Field</u>				
Mosbacher #1 Bd. of Supv. 16-13			NR	353
Mosbacher #1-McRae 21-12	50	0	NC	NC
Dunbar #A-1 Kirkland 29-1	60	10	335	368

<u>Field/Well Name</u>	<u>Norphlet</u>		<u>Smackover</u>	
	<u>Lower</u>	<u>Upper</u>	<u>Lower</u>	<u>Upper</u>
<u>Pachuta Creek Field</u>				
Shell #1-Britton 22-1	55	0	Fault	411
Mosbacher #1-Moore 22-7	49	0	471	431
Shell #1-McCarty 26-10	65	0	418	420
Getty #1 Crook 15-16	55	0	416	Fault
Mosbacher #1-Gibbs	+100	0	NC	NC
<u>Wilcat Wells</u>				
Pruet #1-Goodwin 9-5	30	0	440	390
(Sec 5/1N-14E)				
Shell #1-Shanks 10-7	88	35	350	630
(Sec 10/1N-15E)				
Shell #1-Newton 15-1	100	170	348	613
(Sec 15/1N-15E)				
Harris #1-Evans 4-4	110	180	401	425
(Sec 4/1N-15E)				
Vanghey #1-McClendon-Cox	60	65	300	381
(Sec 30/2N-15E)				
Exchange #1-Evans 6-7	+25	45	288	427
(Sec 6/2N-15E)				
Brandon #1-Taylor 4-14	+50	0	292	404
(Sec 4/2N-15E)				
Shell #1-Freeman 10-10	70	0	427	Fault?
(Sec 10/2N-14E)				
Pan Am #1-Masonite B-1	NR	NR	NR	NR
(Sec 33/3N-15E)				
Sun #1-Bd. of Supv.	?	?	NC	NC
(Sec 16/3N-15E)				
Harris #1-Moore 10-12	50	30	370	250
(Sec 10/3N-14E)				

## VITA

Calvin Lee Badon was graduated from the University of Southwestern Louisiana with a B.S. in Geology in 1958. For three years, he worked for Geophysical Service, Inc. as an exploration geophysicist. From 1961 to 1963, he attended the University of Kansas, receiving the M.S. degree in Geology. During the period 1963 to 1967, he was employed as a petroleum geologist by the Kerr-McGee Corporation in Amarillo, Texas, and New Orleans, Louisiana. In 1967, he enrolled at Louisiana State University as a Ph.D candidate.



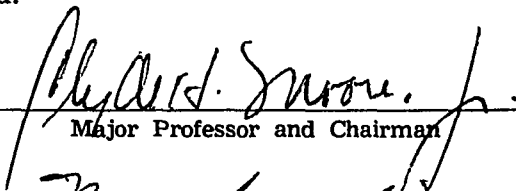
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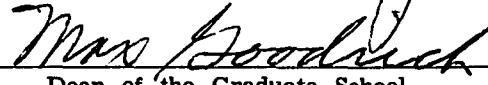
Candidate: Calvin Lee Badon

Major Field: Geology

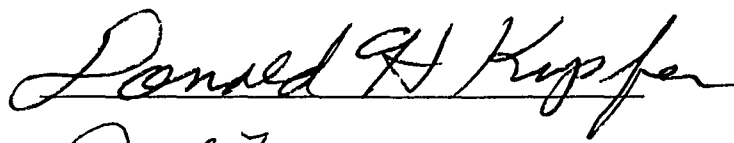
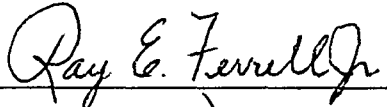
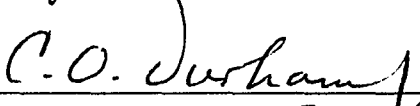
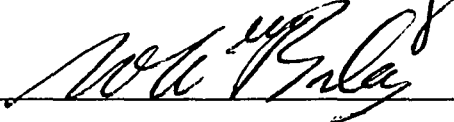
Title of Thesis: Petrology of the Norphlet and Smackover Formations  
(Jurassic); Clarke County, Mississippi.

Approved:

  
Major Professor and Chairman

  
Dean of the Graduate School

## EXAMINING COMMITTEE:

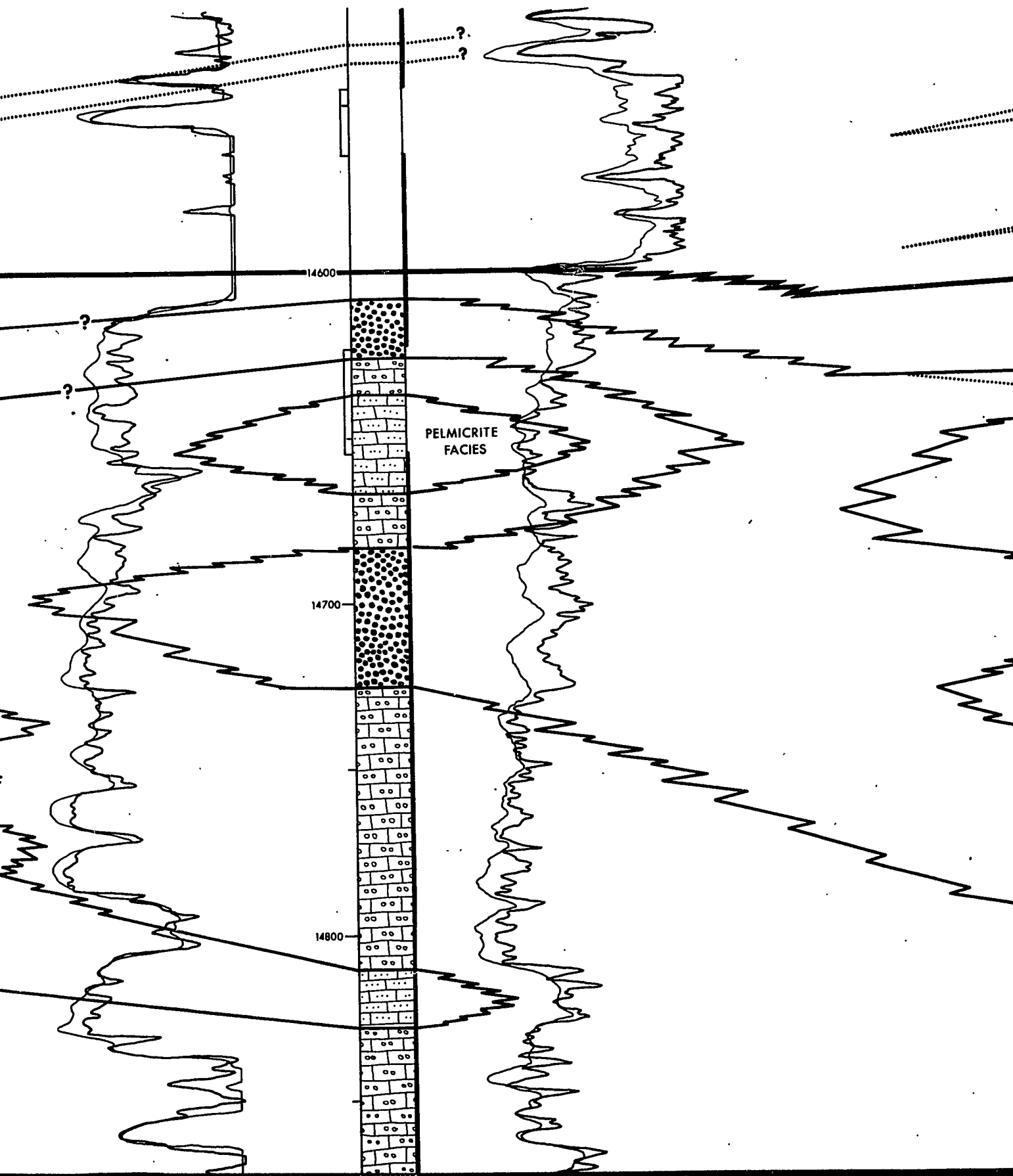
Date of Examination:

March 28, 1973

WATER FIELD

Shell #1 - Thomas

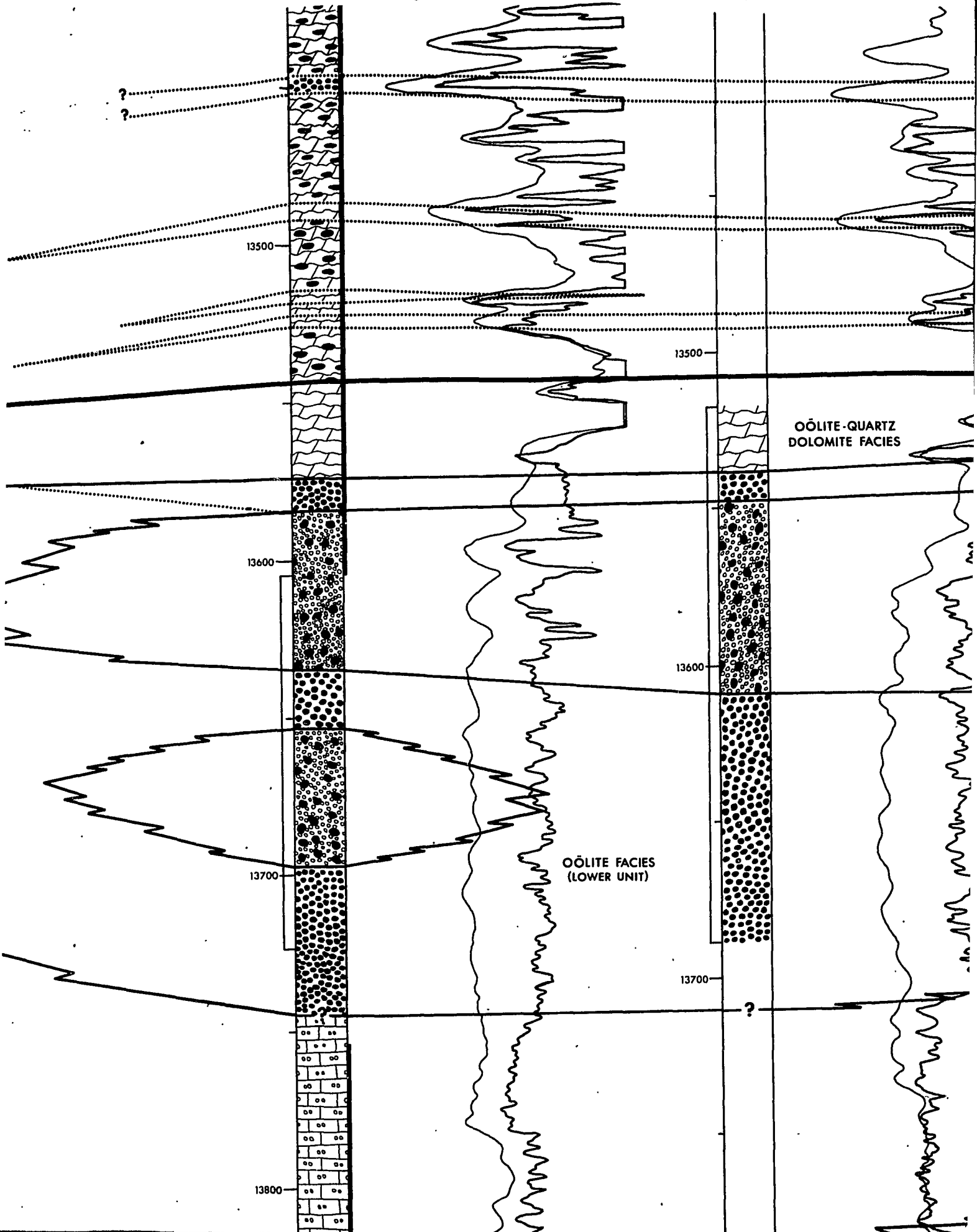
Shell #1 - Johnston



EAST NANCY FIELD'

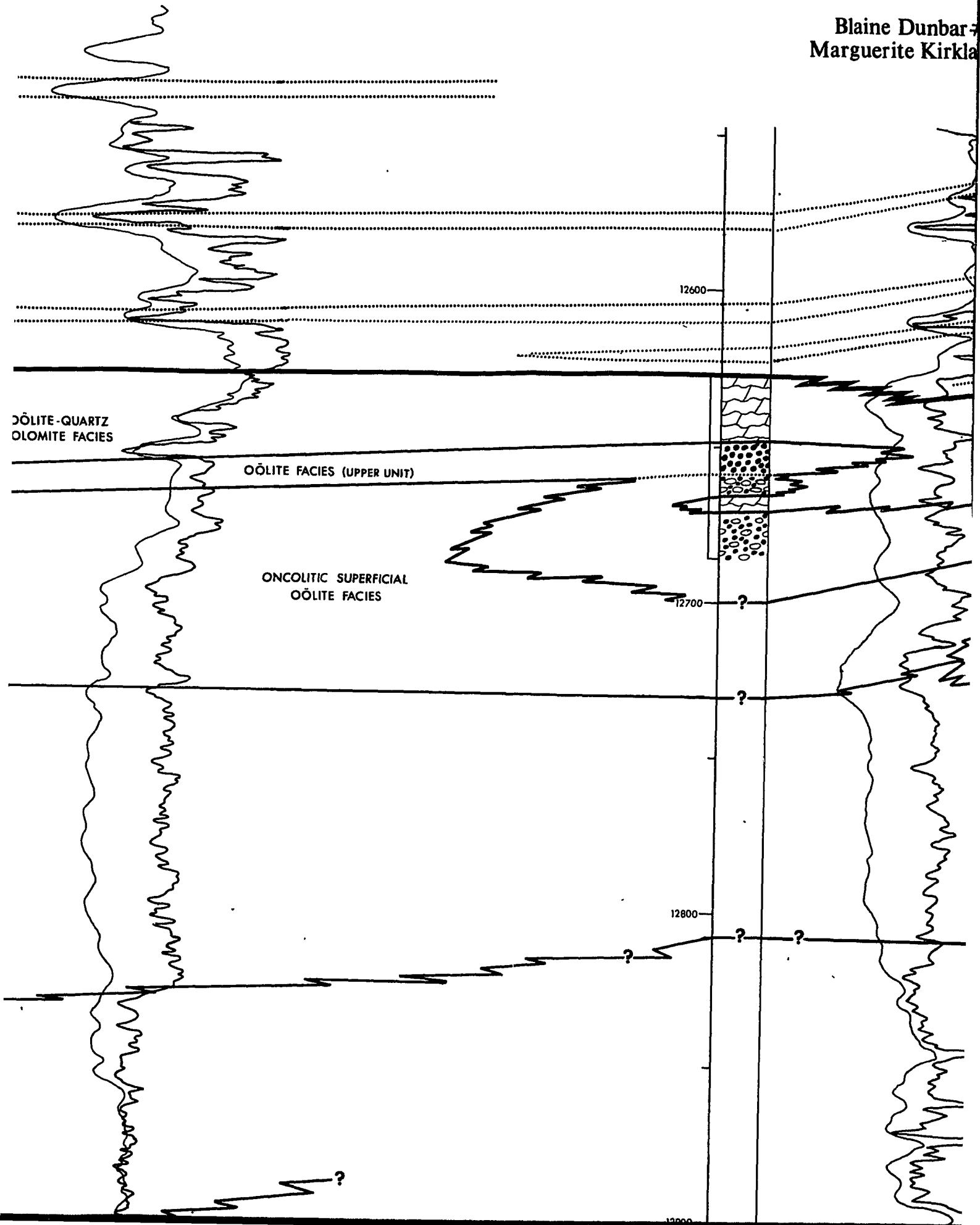
**Getty#1 - Masonite 17-13.**

**Getty #1 - Masonite 18**



y #1 - Masonite 18-8

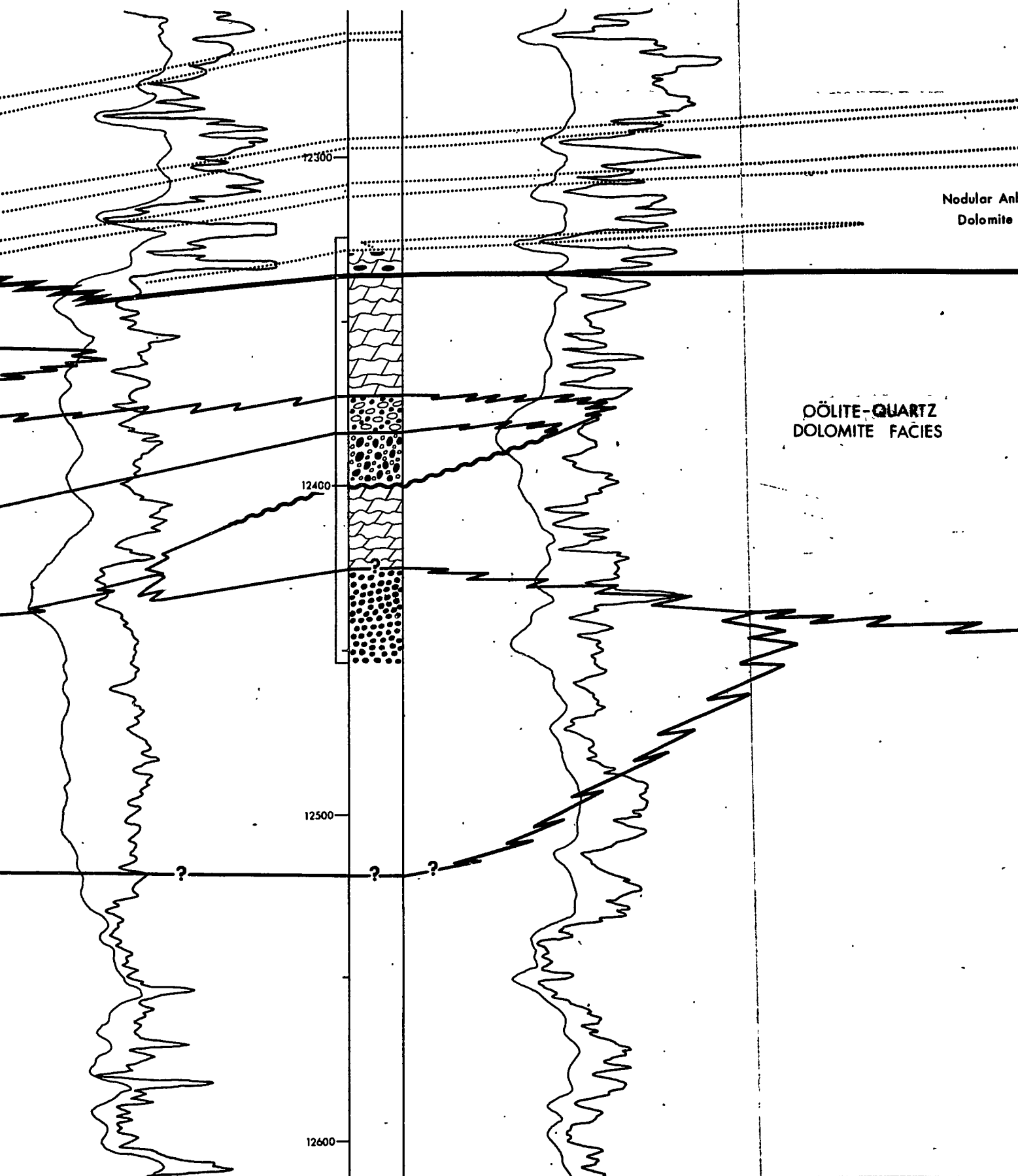
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Marguerite Kirkla



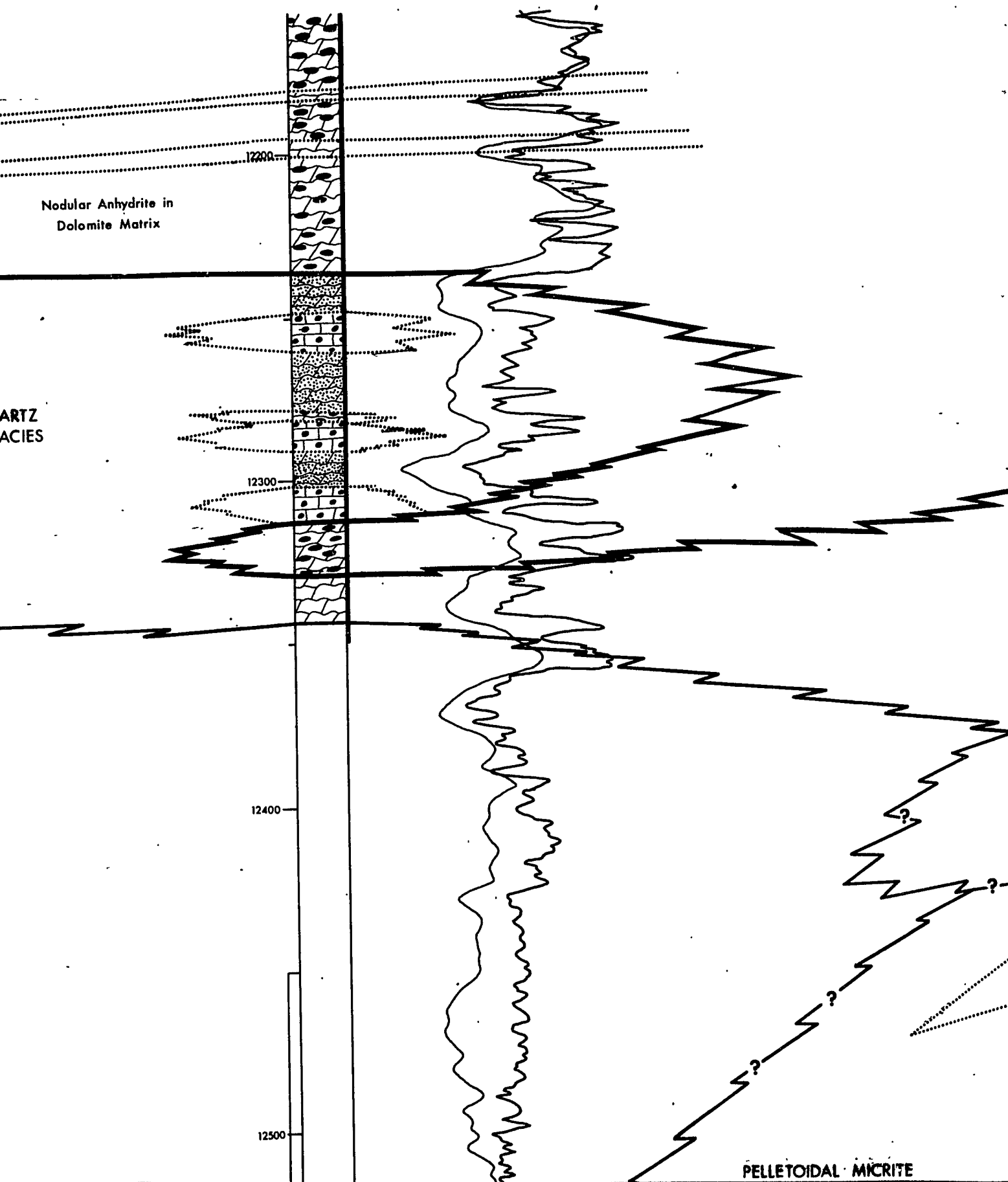
# HARMONY FIELD

Blaine Dunbar #1-A  
Marguerite Kirkland 29-1

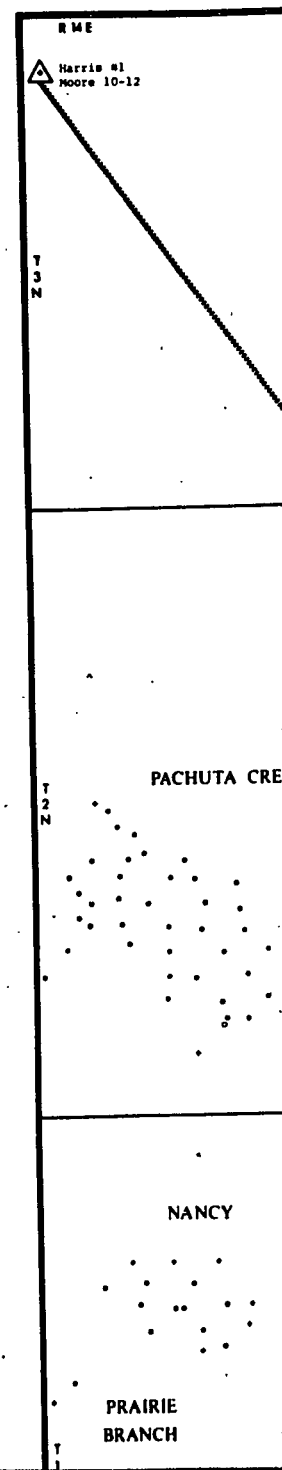
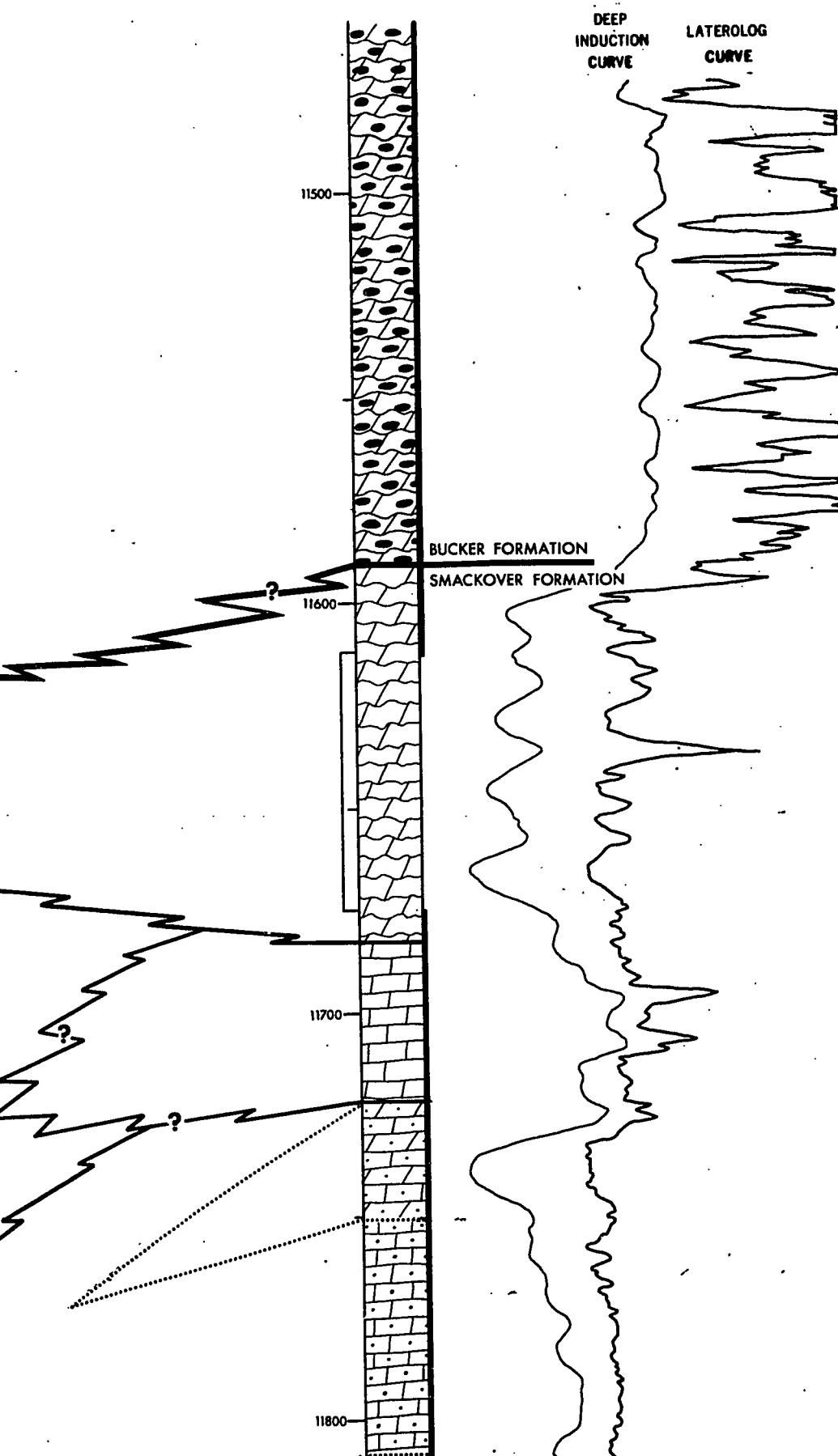
Mosbacher #1 -  
Board of Supervisors 16-13

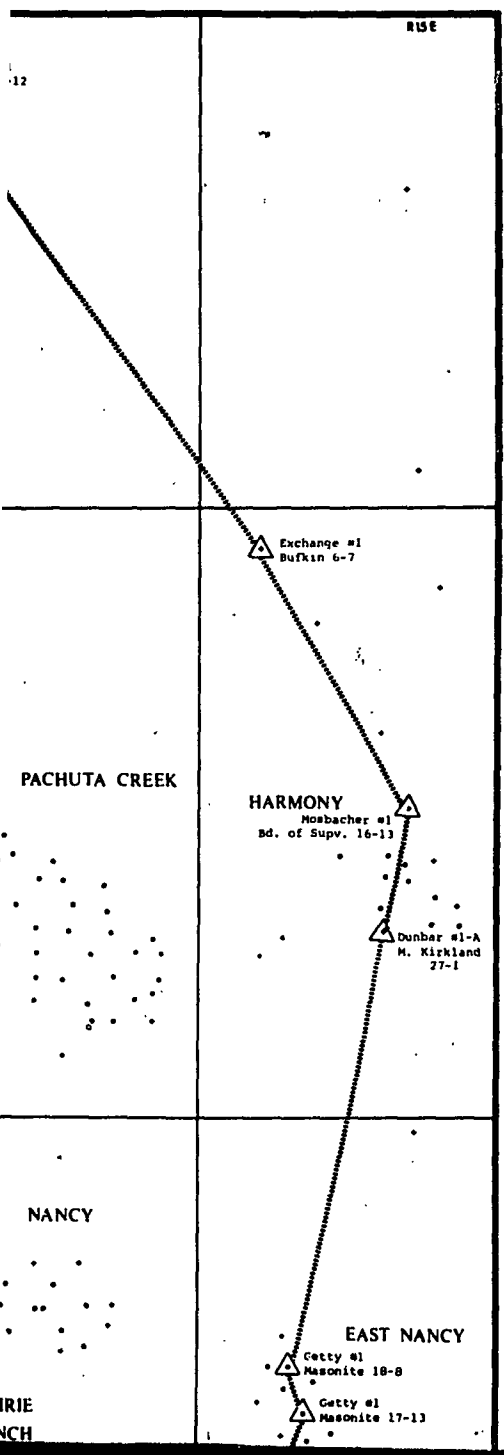


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Section 6, 2N-15E

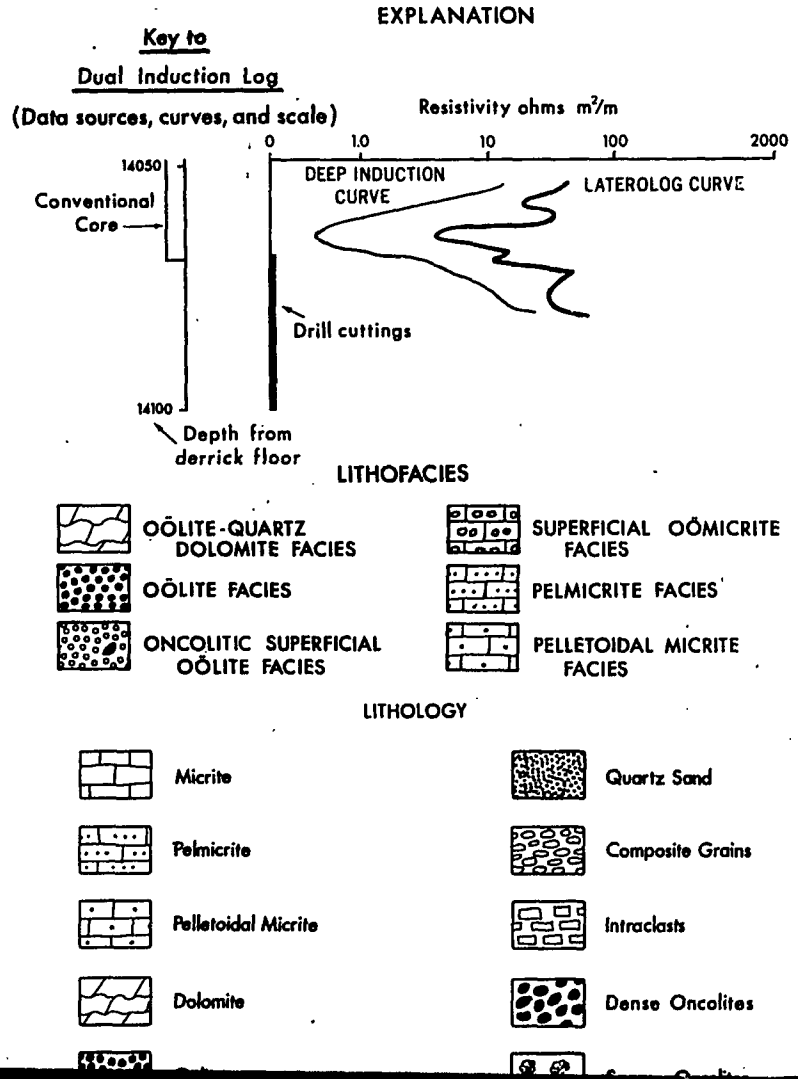


Harris #1 - Moore 10-12  
Section 10, 3N-14E

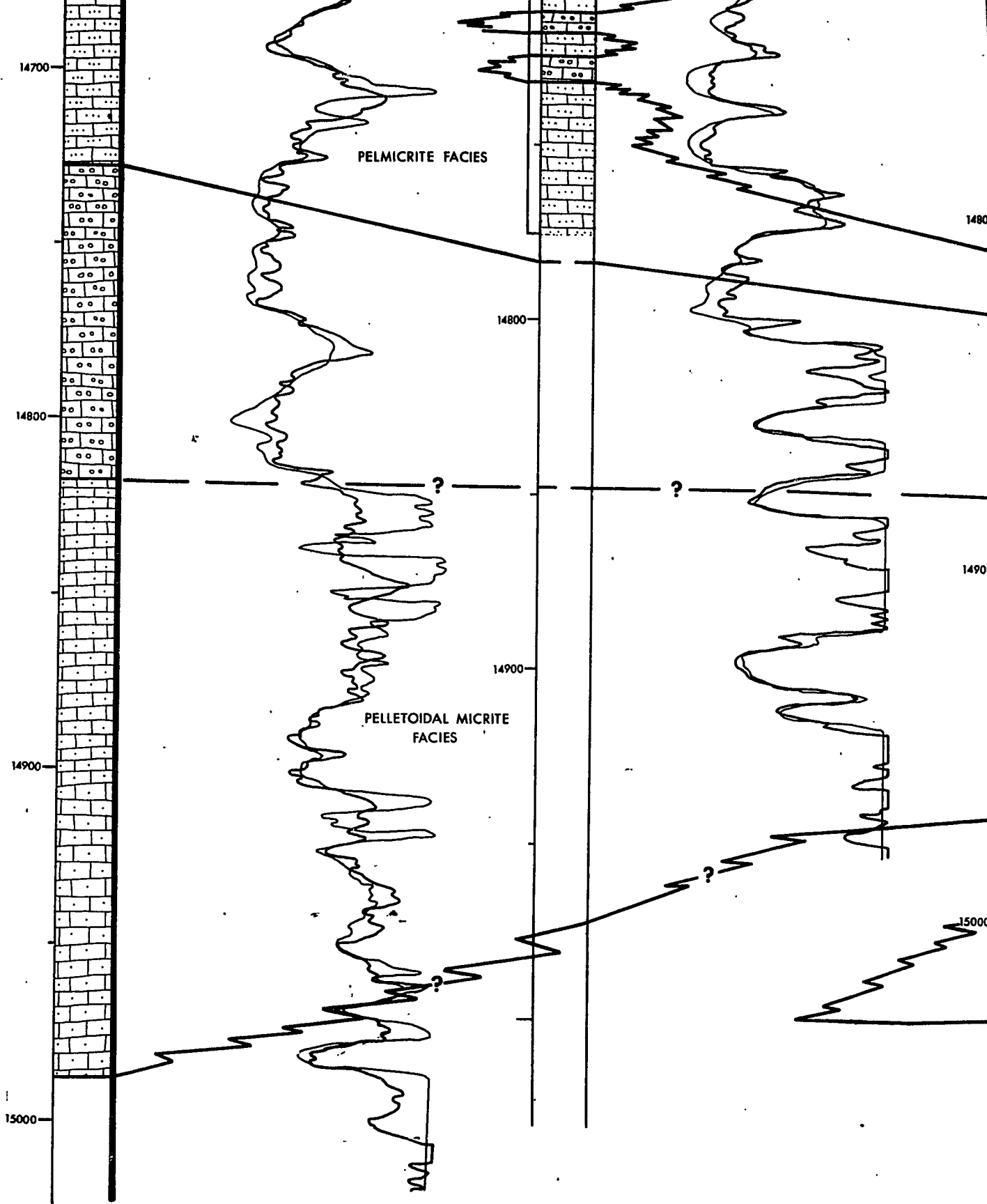


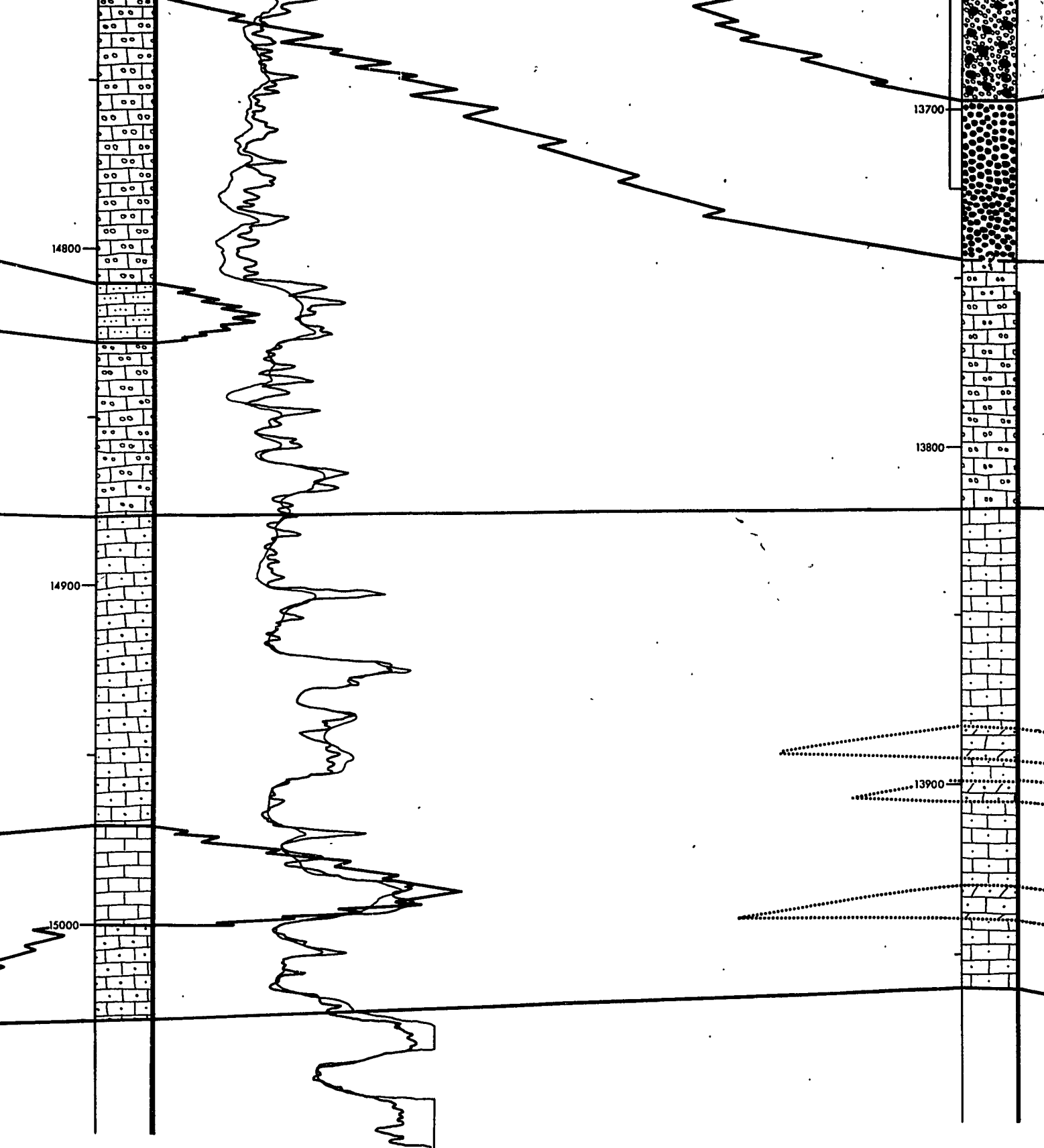


# Stratigraphic Cross-Section UPPER MEMBER, SMACKOVER FORMATION







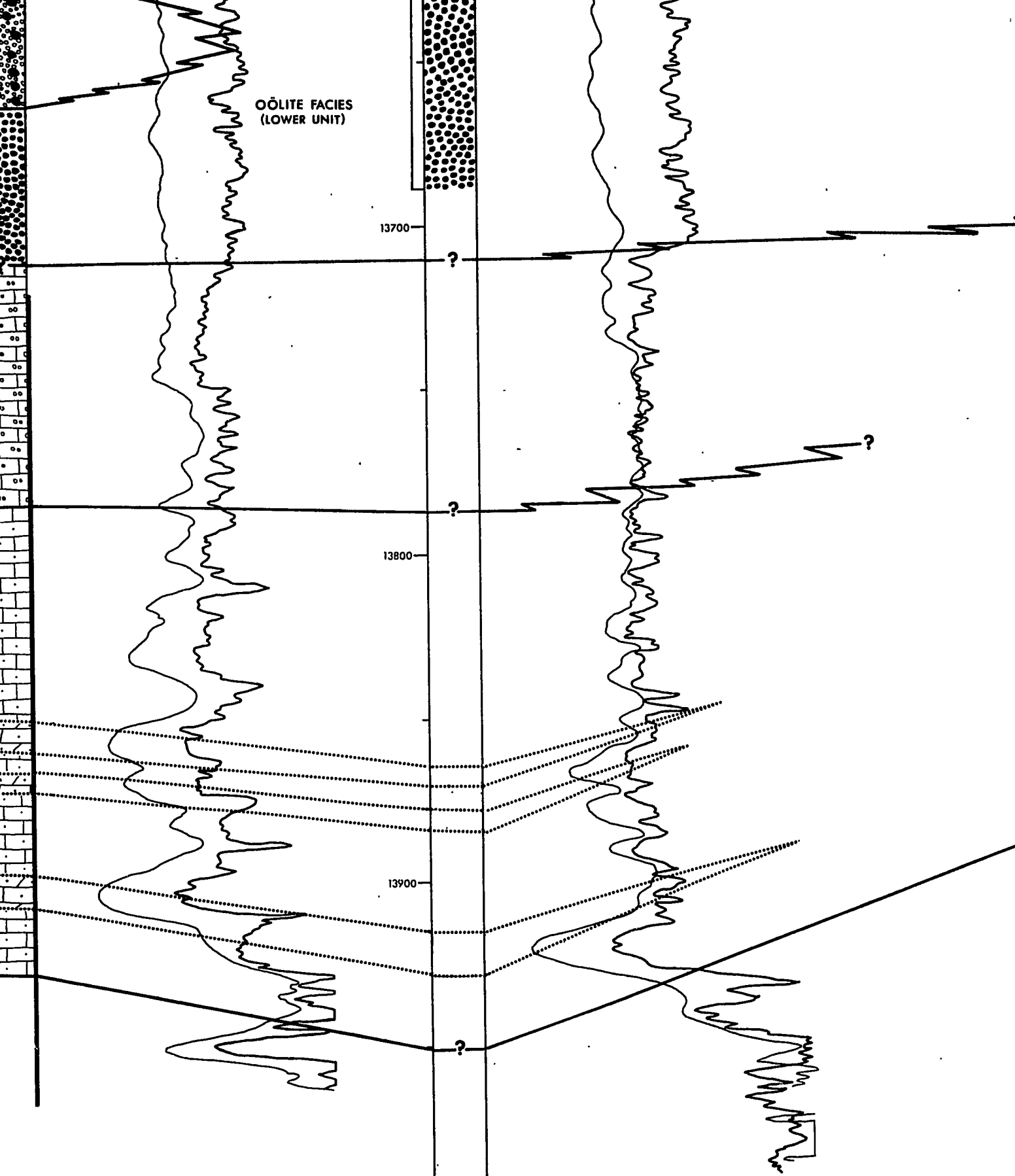


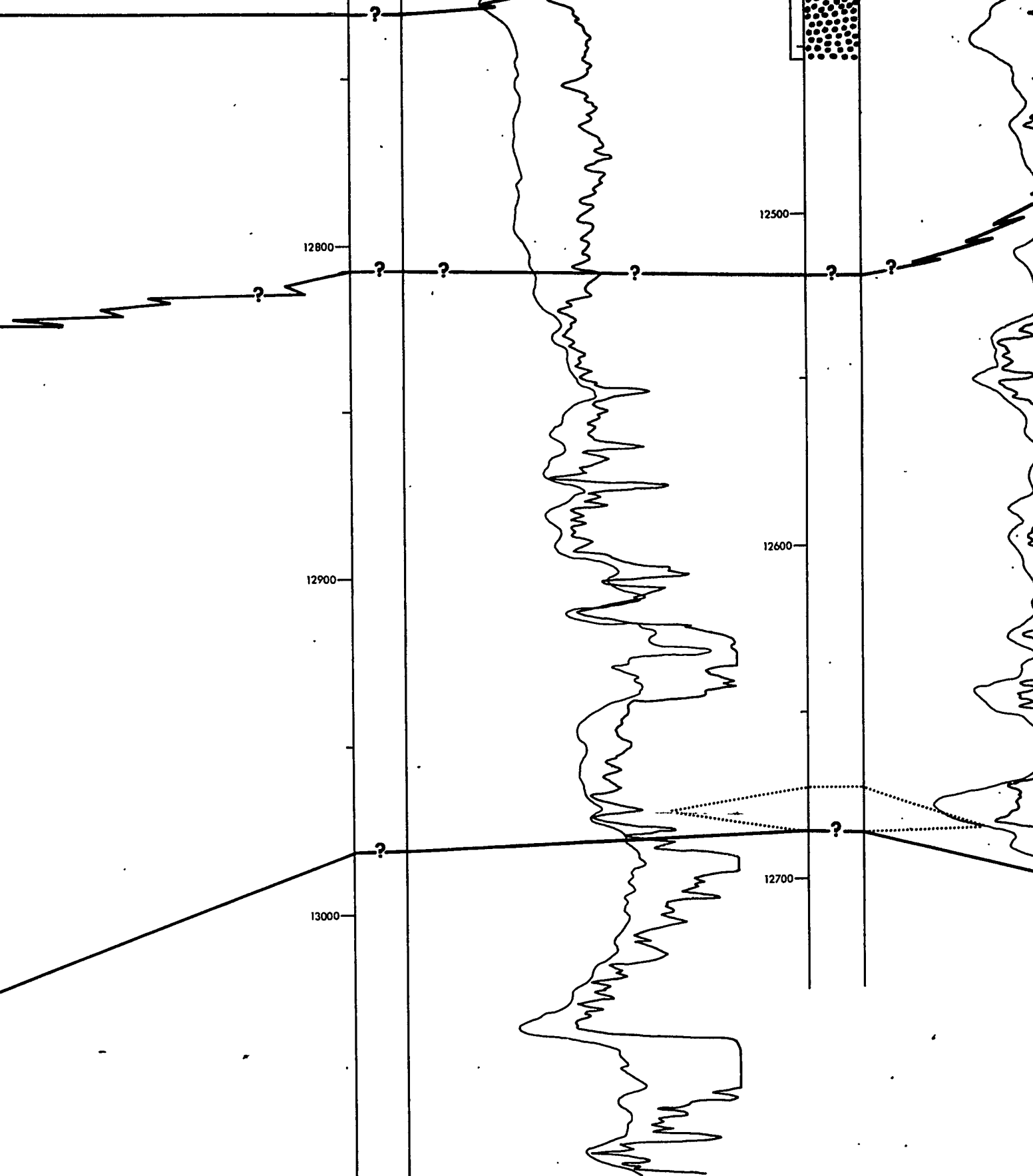
OÖLITE FACIES  
(LOWER UNIT)

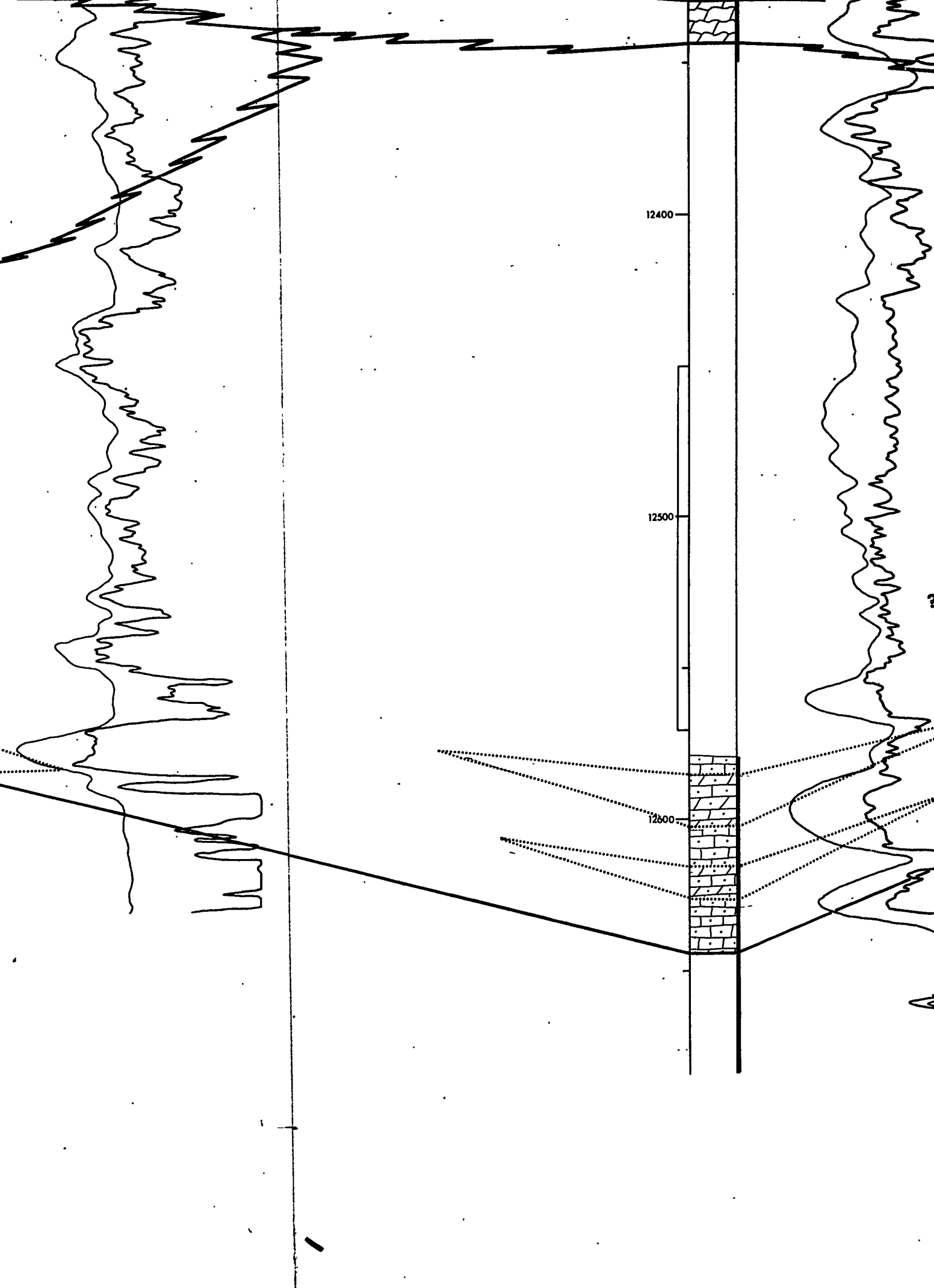
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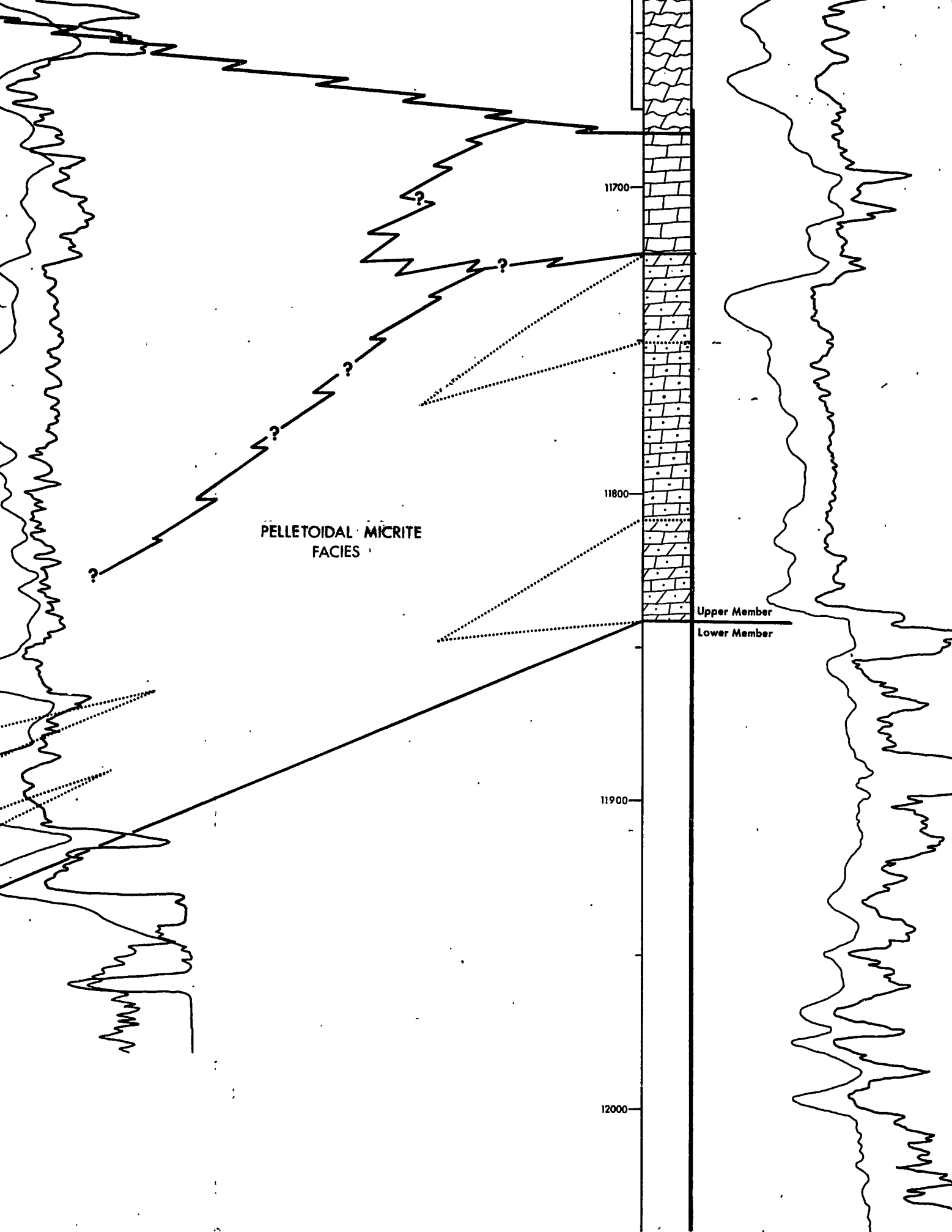
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13900

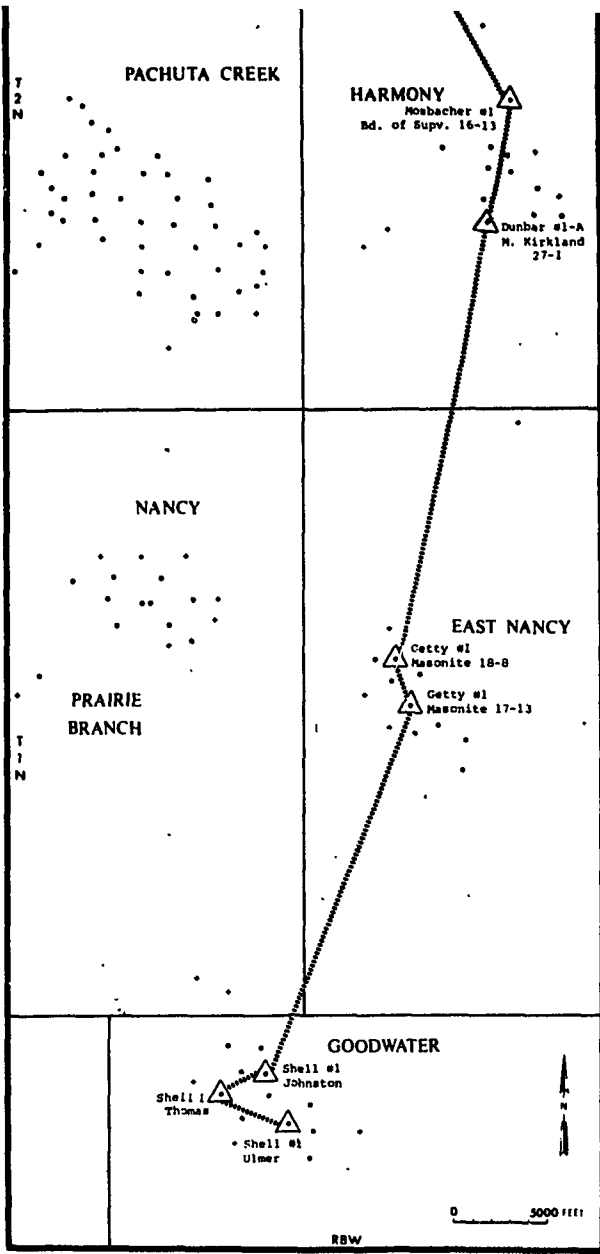



















Handwritten notes on the left margin, including a large 'M' and several lines of illegible scribbles.



- 14100  
De  
der
-  OOLITE
  -  DO
  -  OOLITE
  -  ONCC
  -  OOLITE
  -  M
  -  Pel
  -  Pel
  -  De
  -  O
  -  Su

14100  
Depth from  
derrick floor

# LITHOFACIES



OOLITE-QUARTZ  
DOLOMITE FACIES



OOLITE FACIES



ONCOLITIC SUPERFICIAL  
OOLITE FACIES



SUPERFICIAL OOLMICRITE  
FACIES



PELMICRITE FACIES



PELLETOIDAL MICRITE  
FACIES

## LITHOLOGY



Micrite



Pelmicrite



Pelletoidal Micrite



Dolomite



Oolites



Superficial Oolites



Quartz Sand



Composite Grains



Intraclasts



Dense Oncolites



Spongy Oncolites



Fossils



Nodular Anhydrite

## BOUNDARY LINE EXPLANATION

Formation Boundary

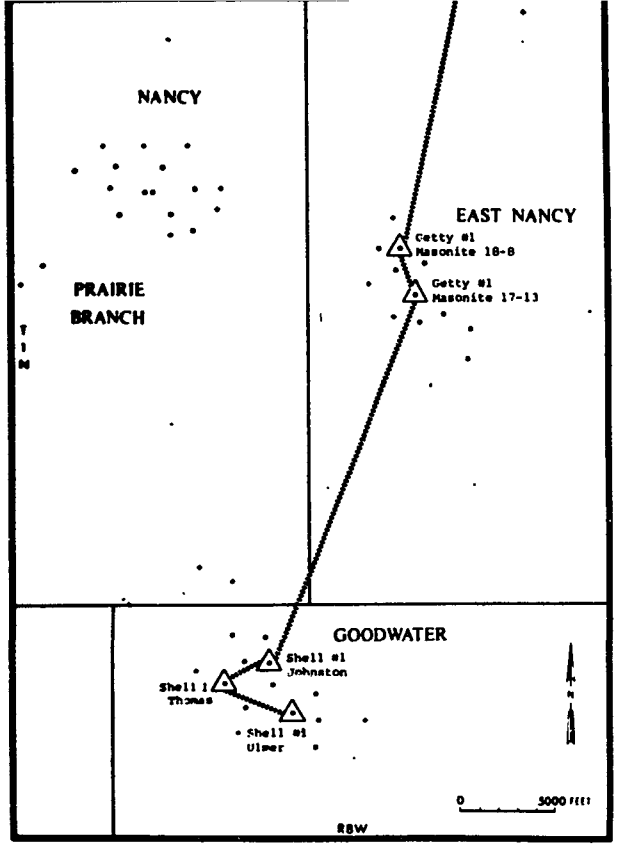
Facies Boundary

Lithologic Boundary

Local Erosion Surface

# PLATE III





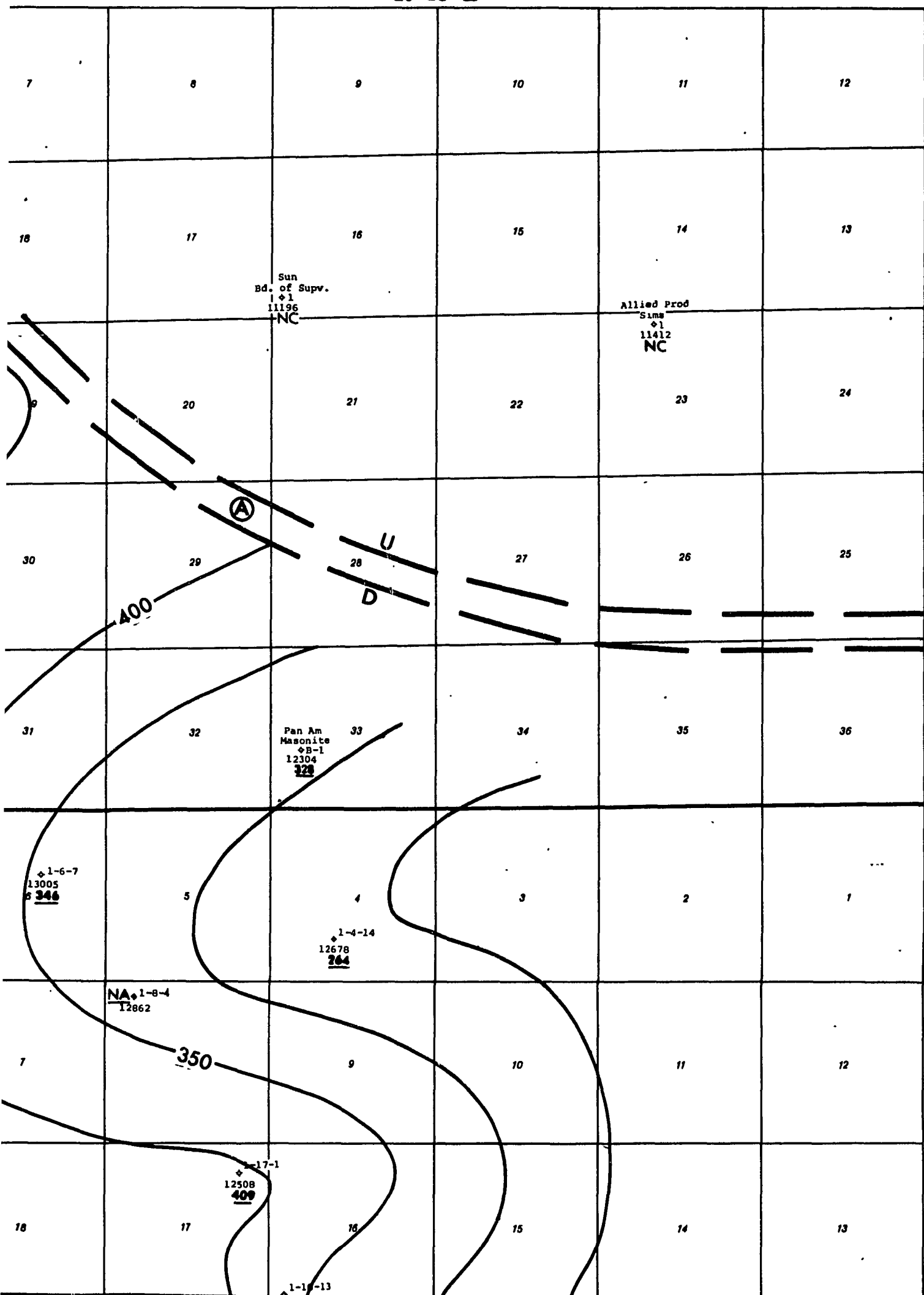
INDEX MAP

R 14 E

T  
3  
N

T

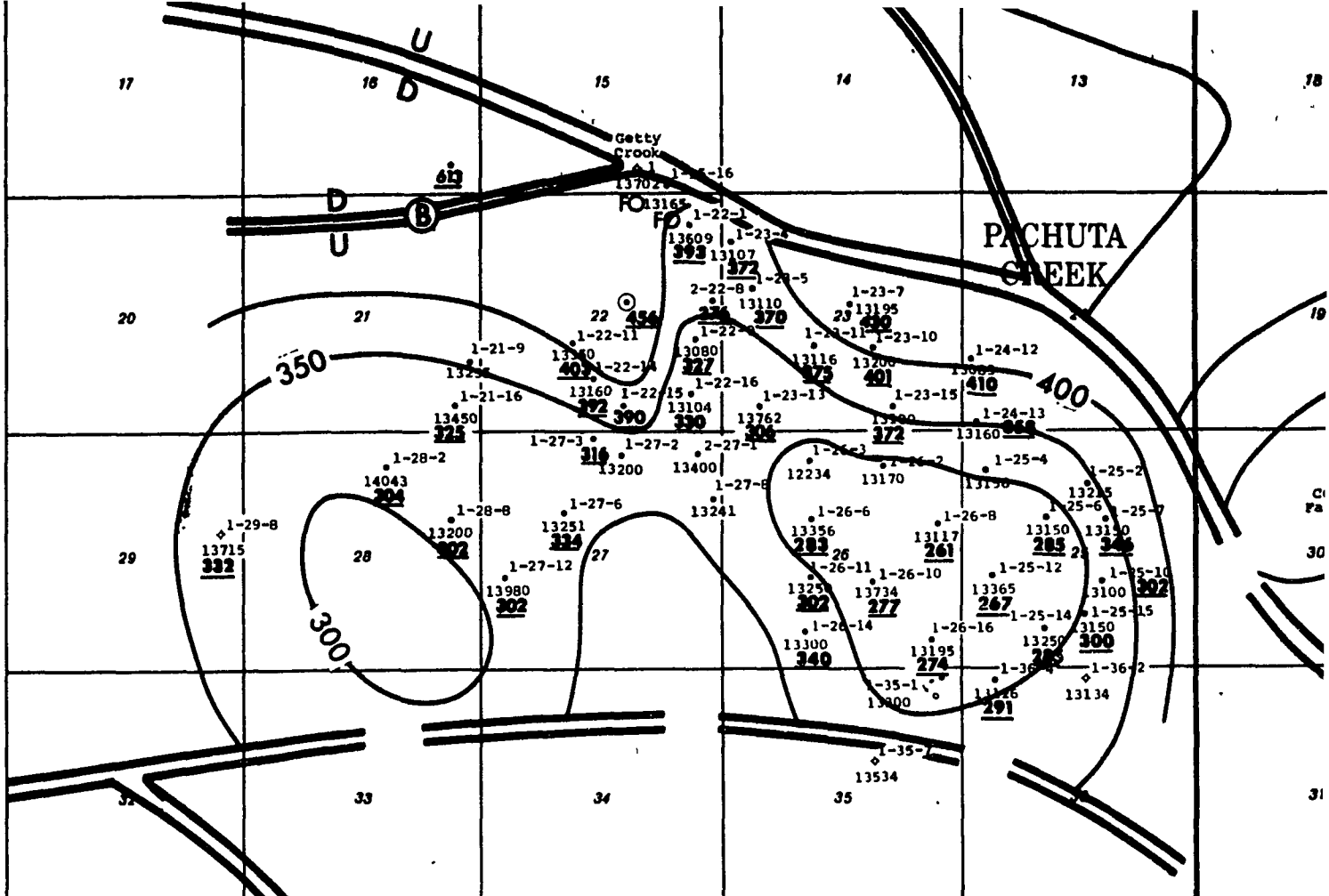




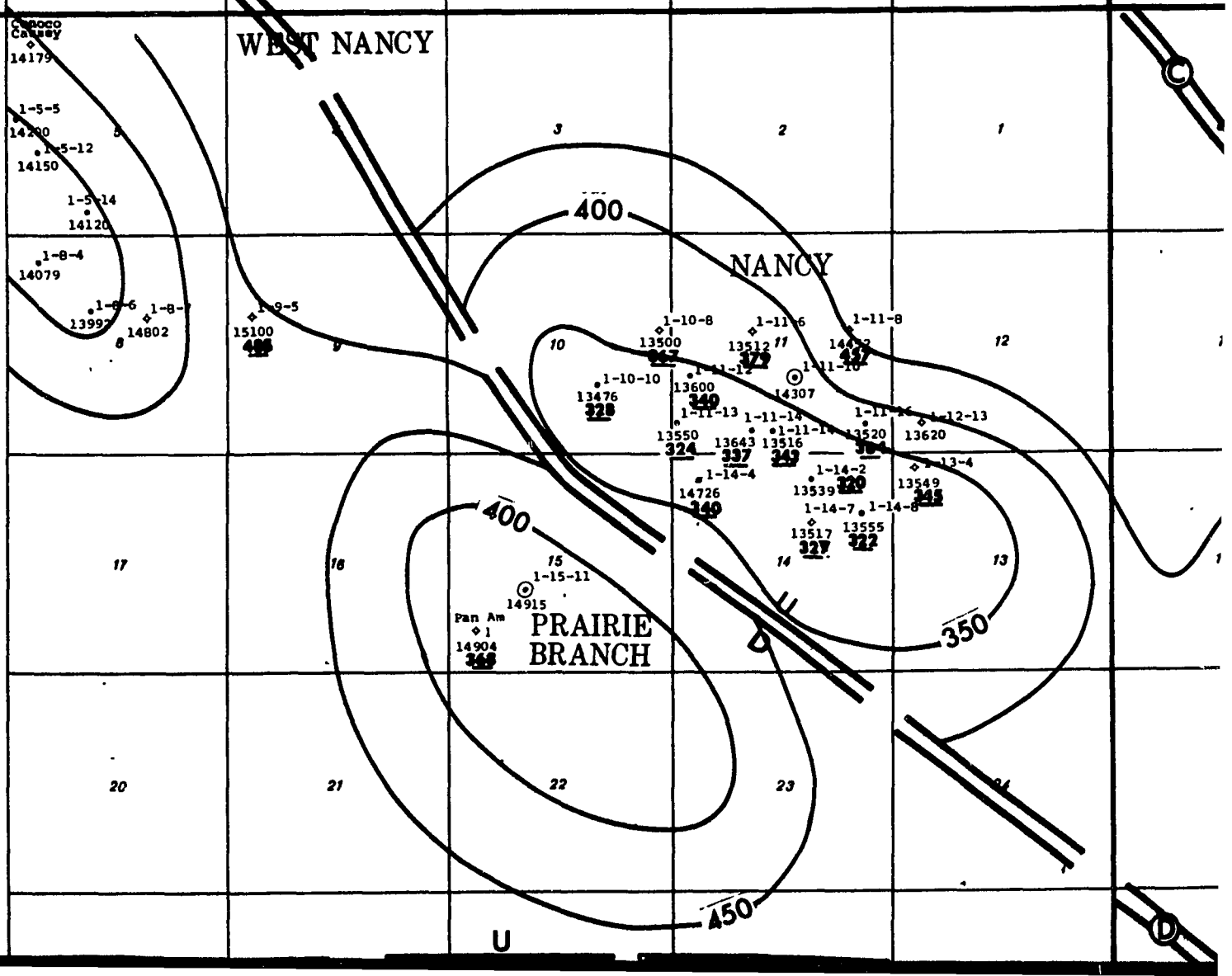
T  
3  
N

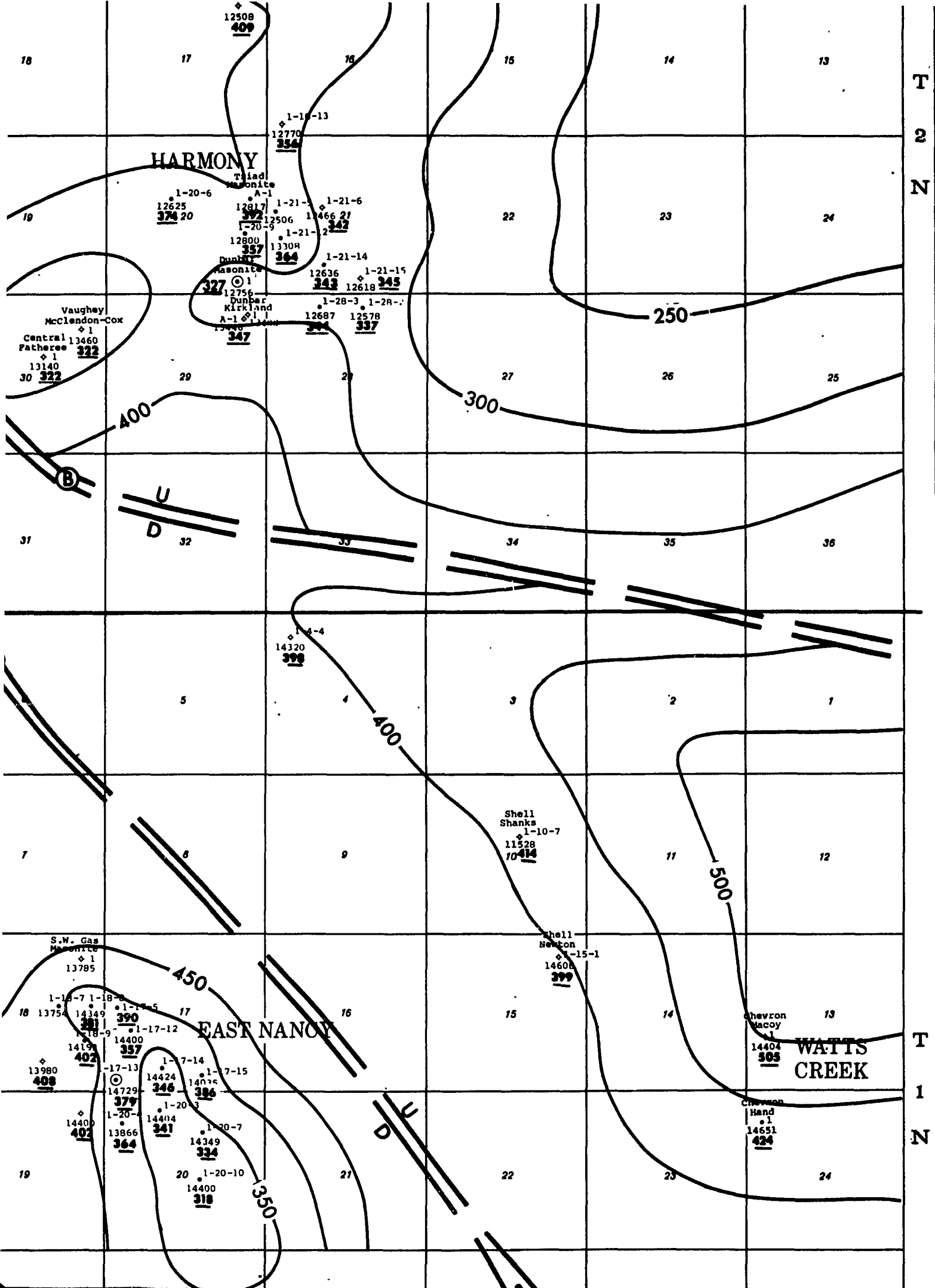
T

T  
2  
N



T  
1  
N





T  
1  
N

T  
10  
N

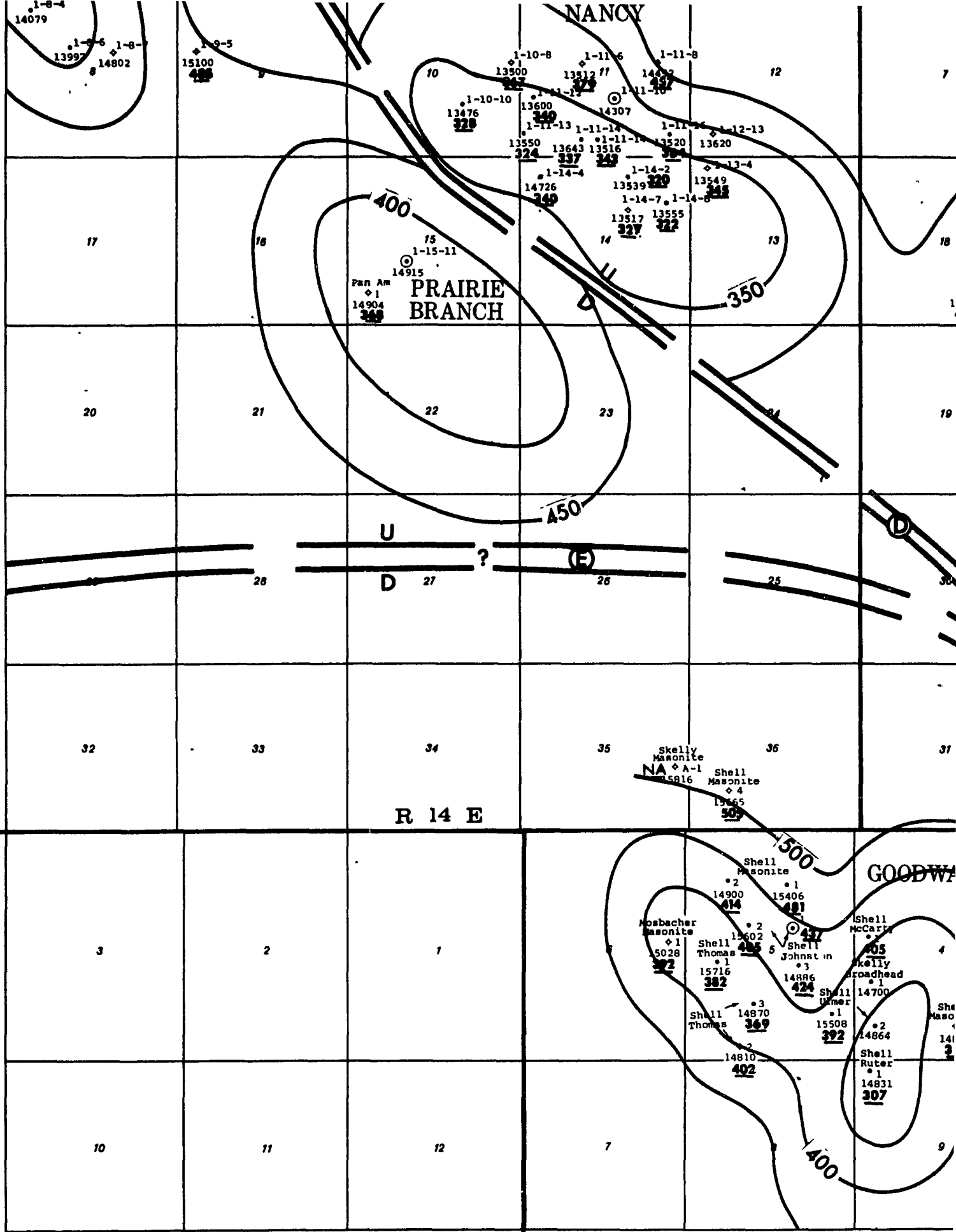
R 9 W

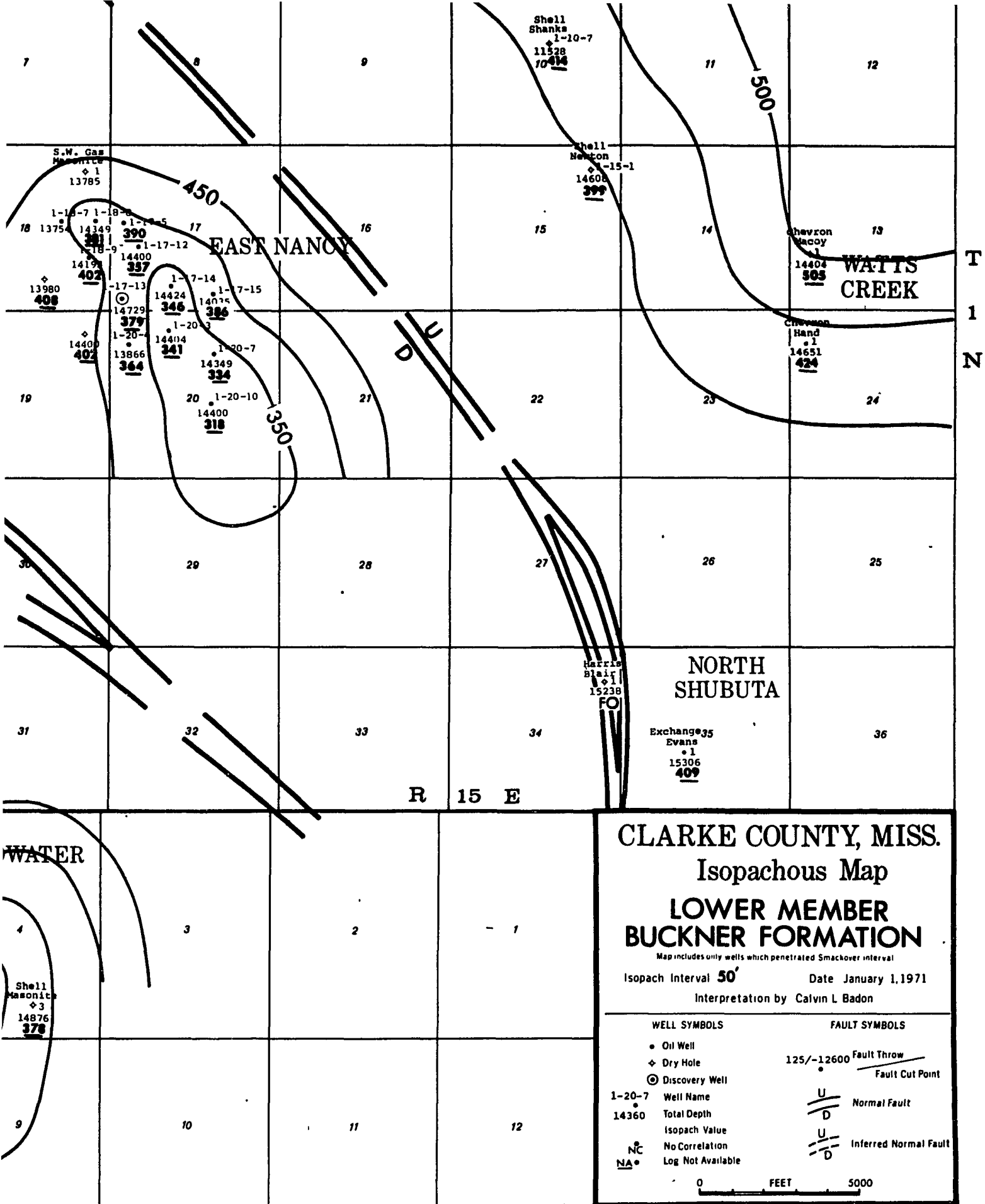
R 14 E

PRAIRIE  
BRANCH

NANCY

GOODWIN





T  
3  
N

T

1-10-12  
12278  
-11233

-11400

-11600

-12200

80/-12500

1-10-10

13470

-12361

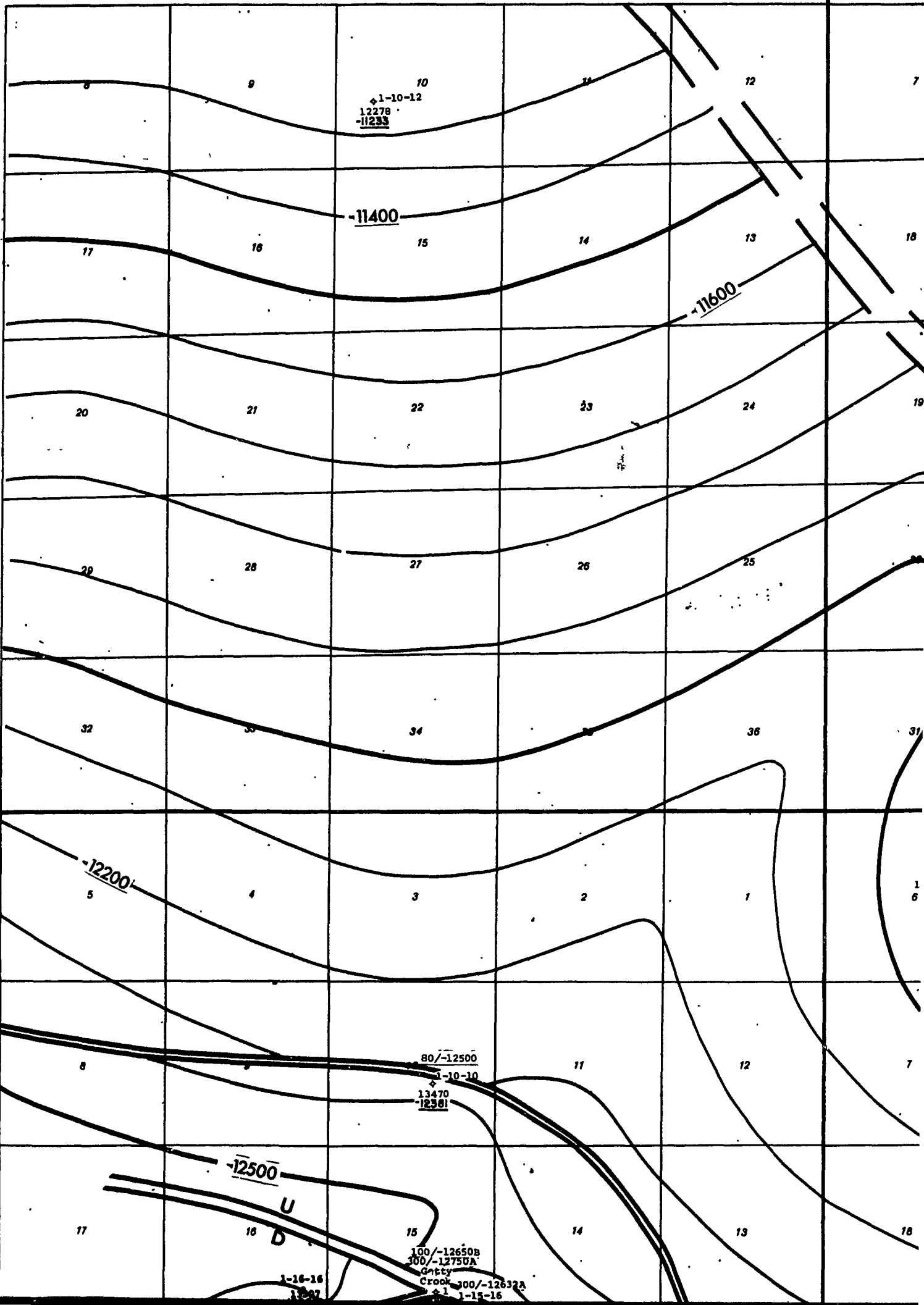
-12500

U

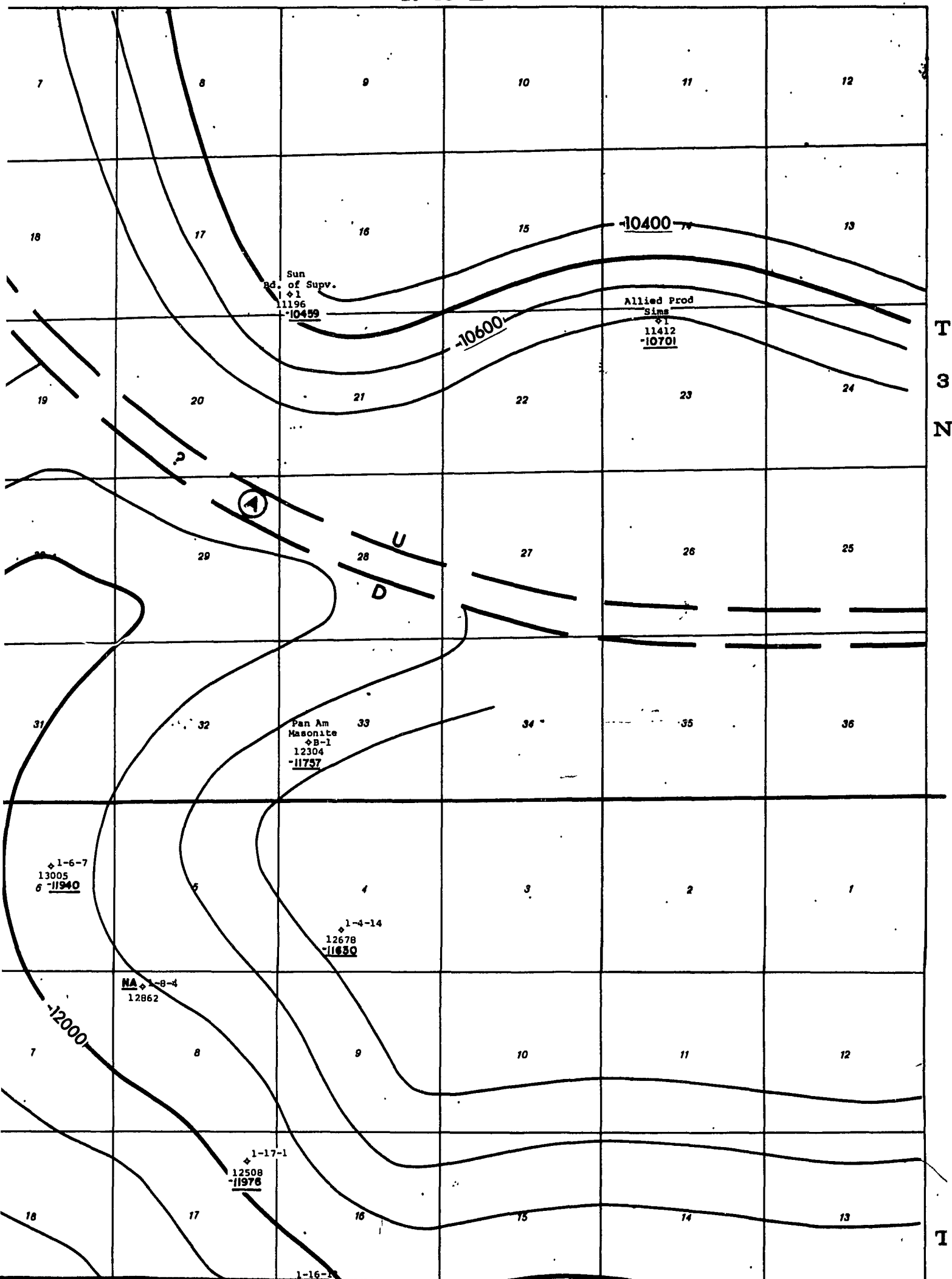
D

100/-12650B  
100/-12750A  
Catty  
Crook 100/-12632A  
1-15-16

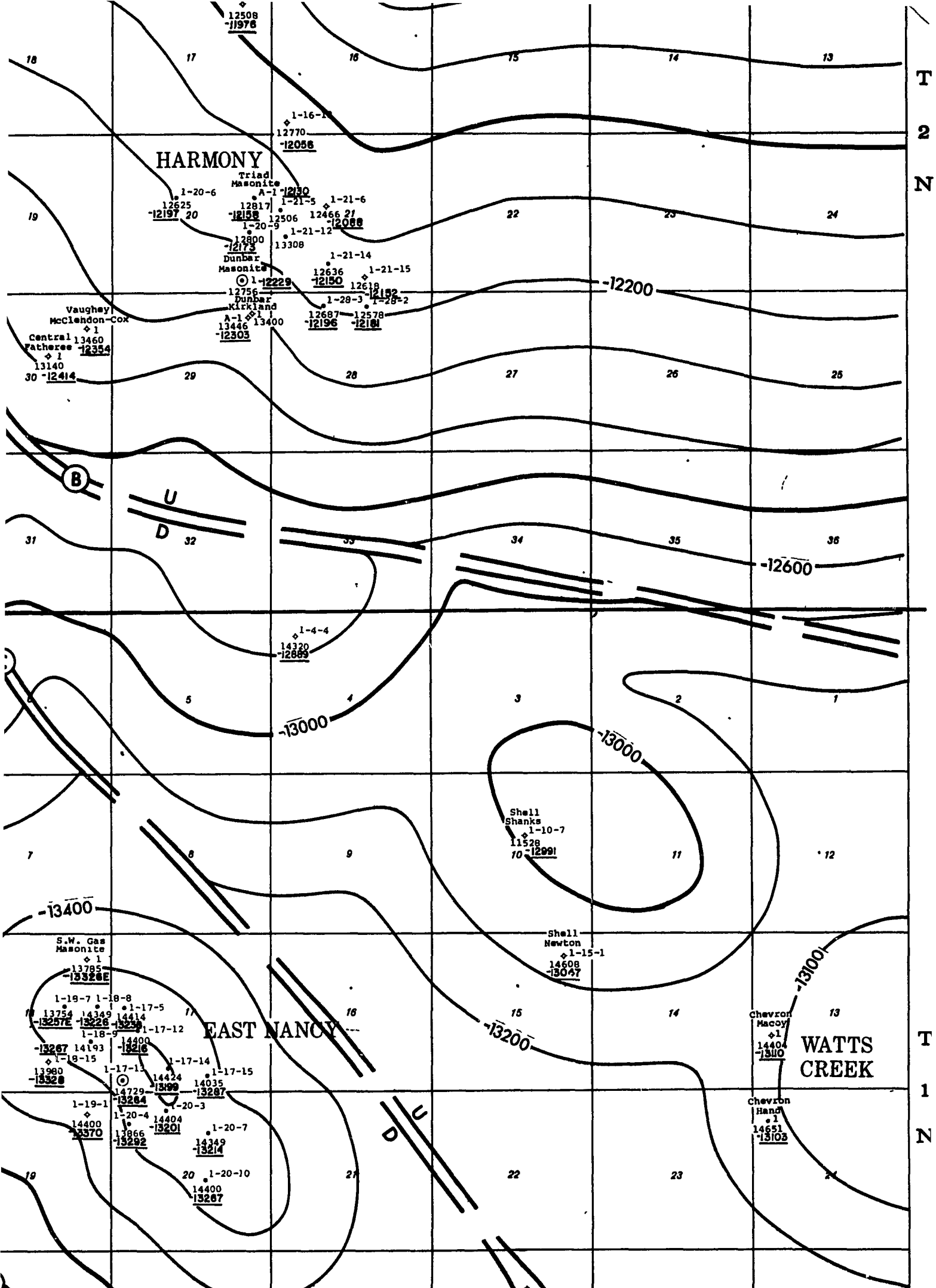
1-16-16  
1-15-16

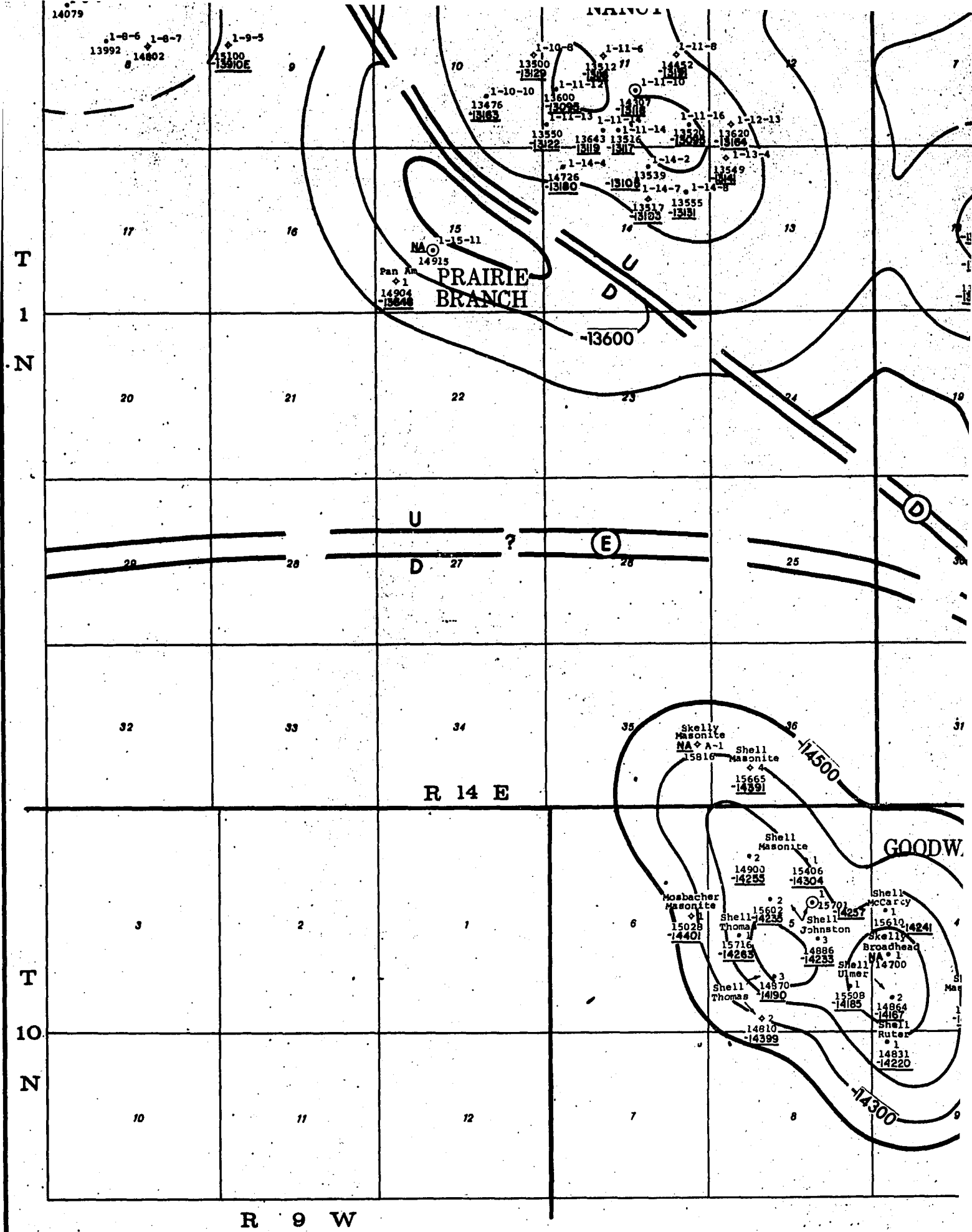






**T  
.  
1  
N**





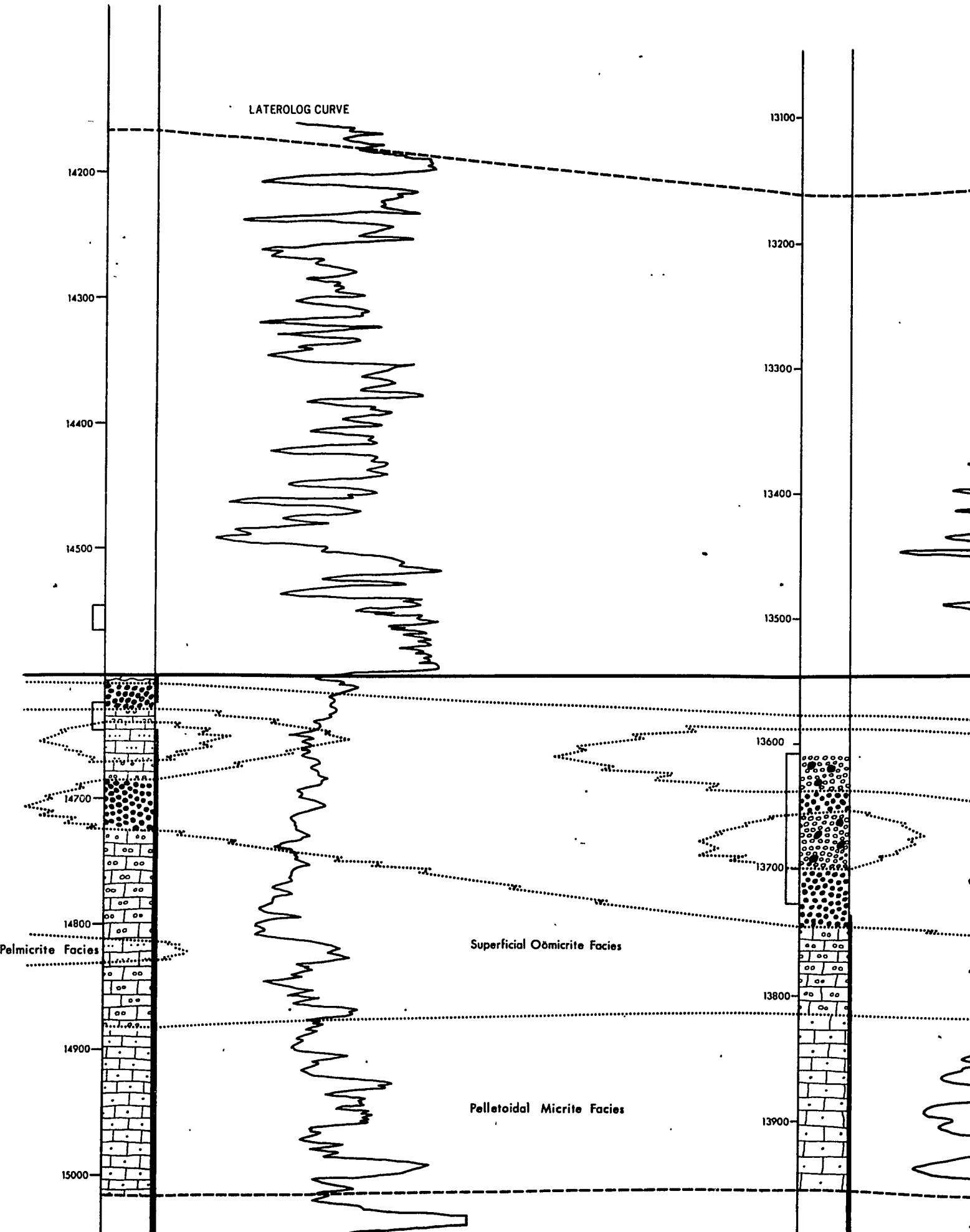


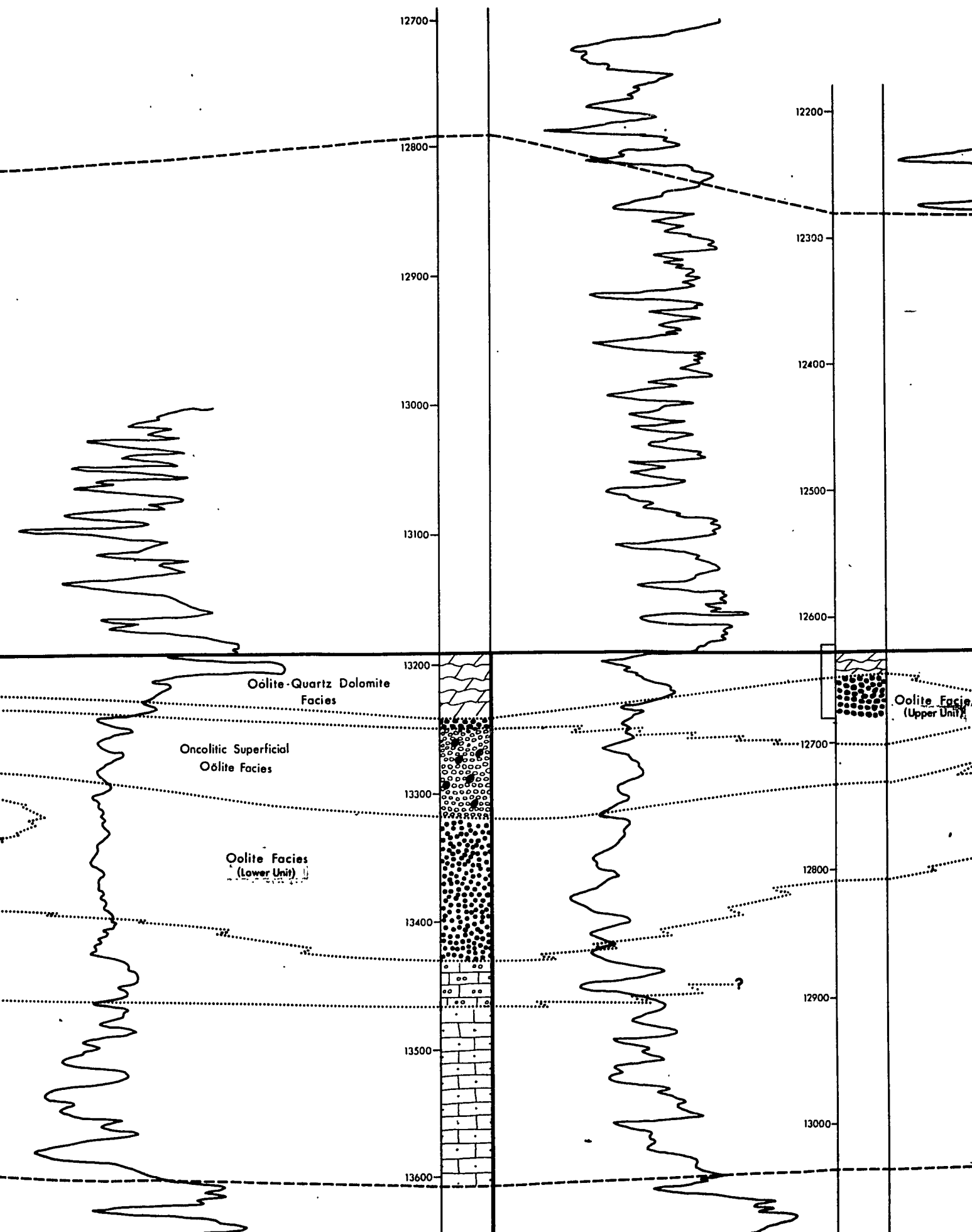
SHELL #1-JOHNSTON

5-10N-8W

GETTY #1-MASON

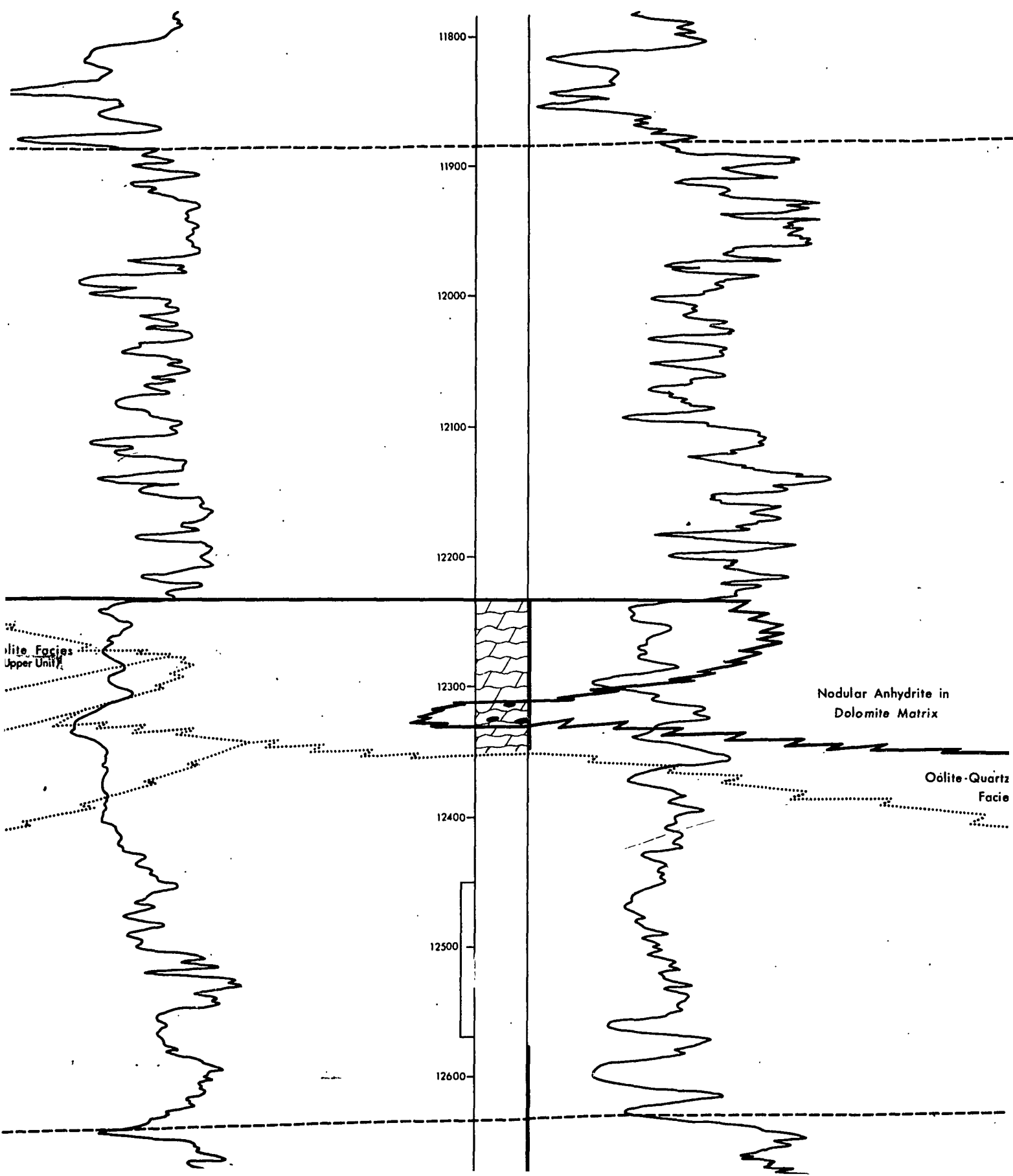
17-1N-15E





#1-A-M. KIRKLAND  
29-2N-15E

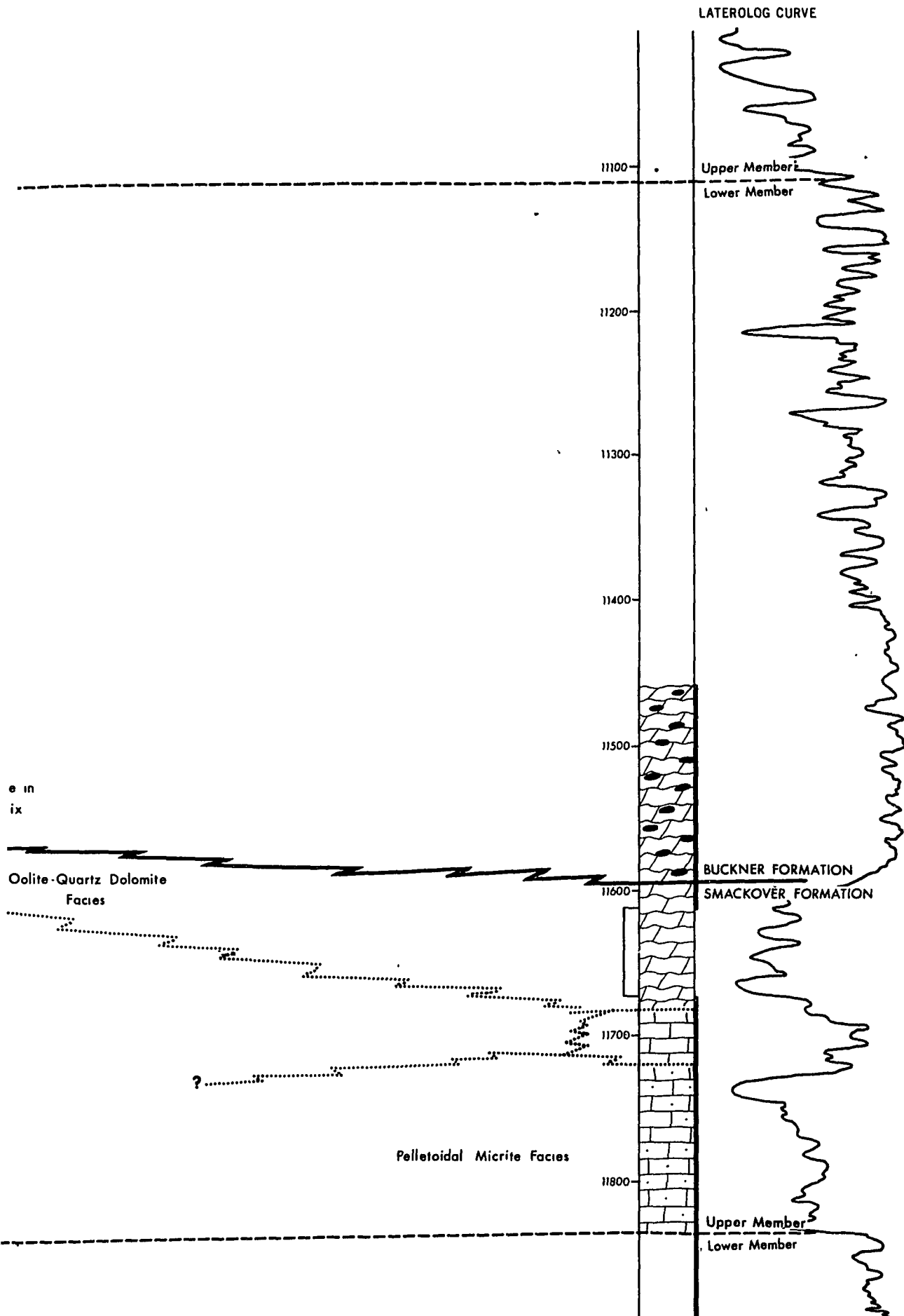
EXCHANGE #1-BUFKIN 6-7  
6-2N-15E

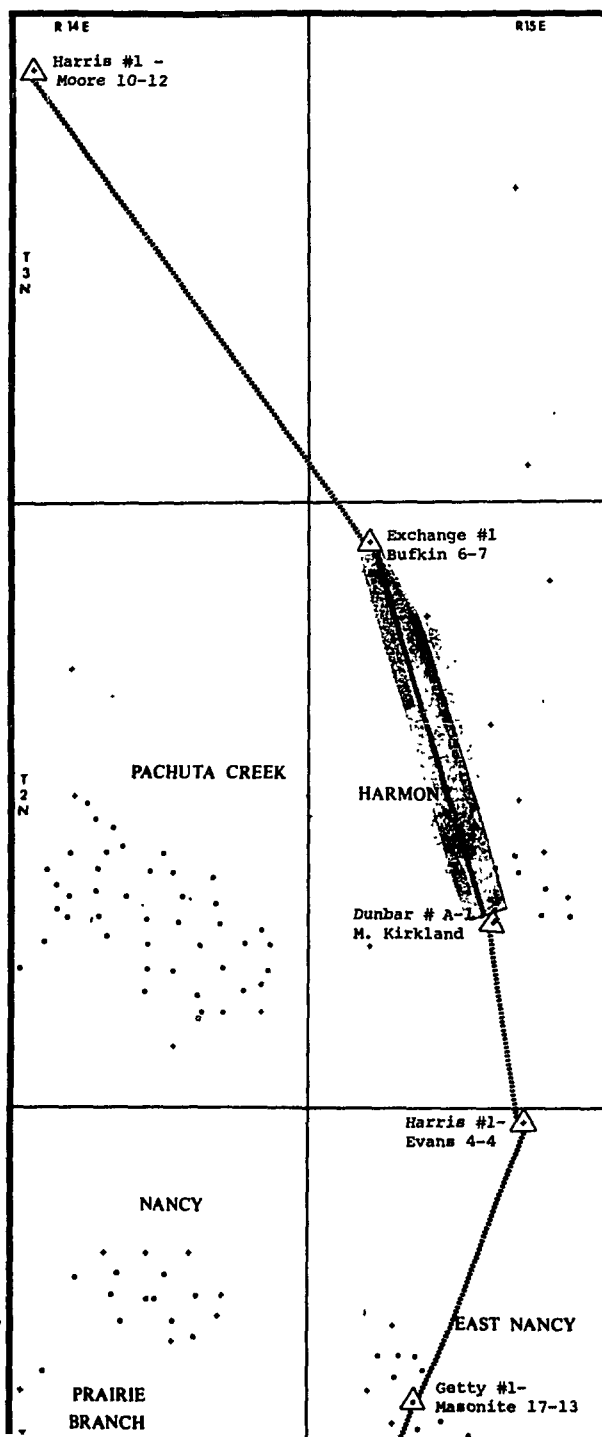




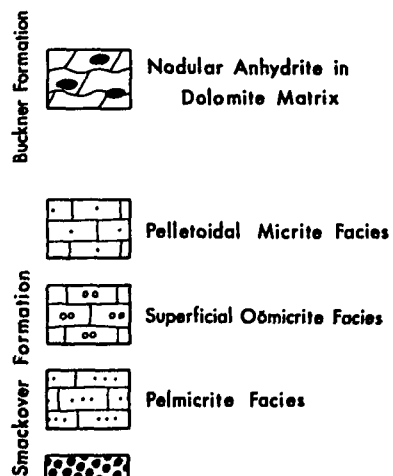
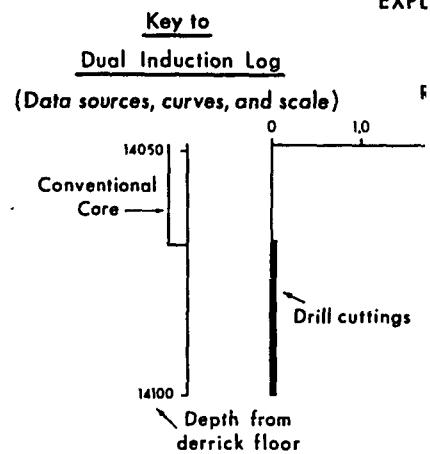
# HARRIS #1-MOORE 10-12

10 - 3N - 14 E

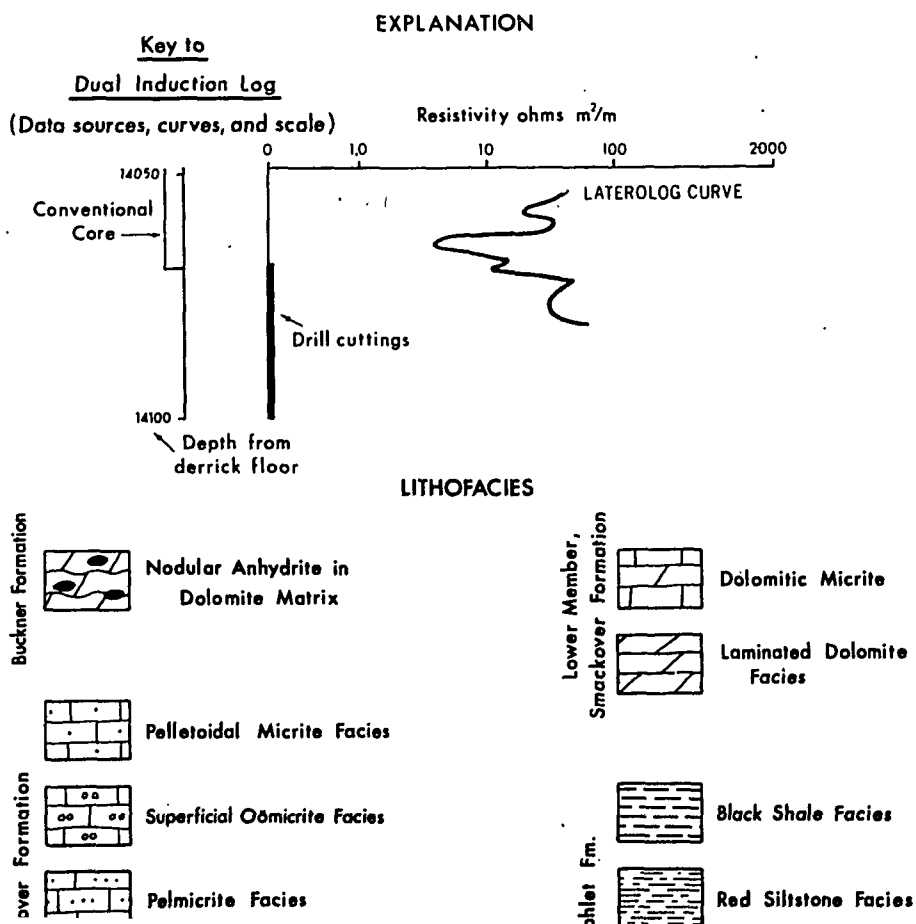




# Reg Stratigraphic NORPHLET-SMA FORM



# Regional Stratigraphic Cross-Section NORPHLET-SMACKOVER-BUCKNER FORMATION

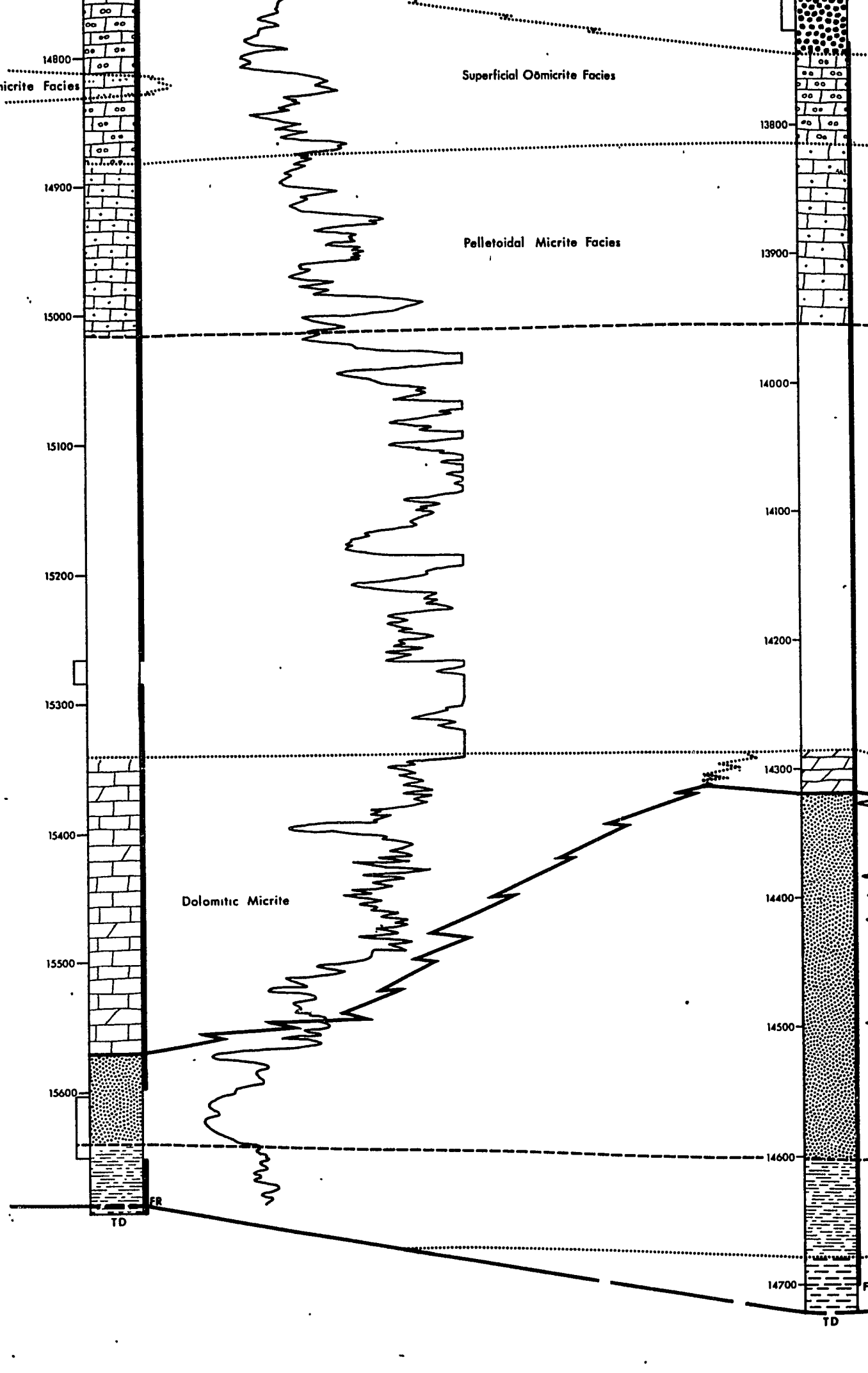


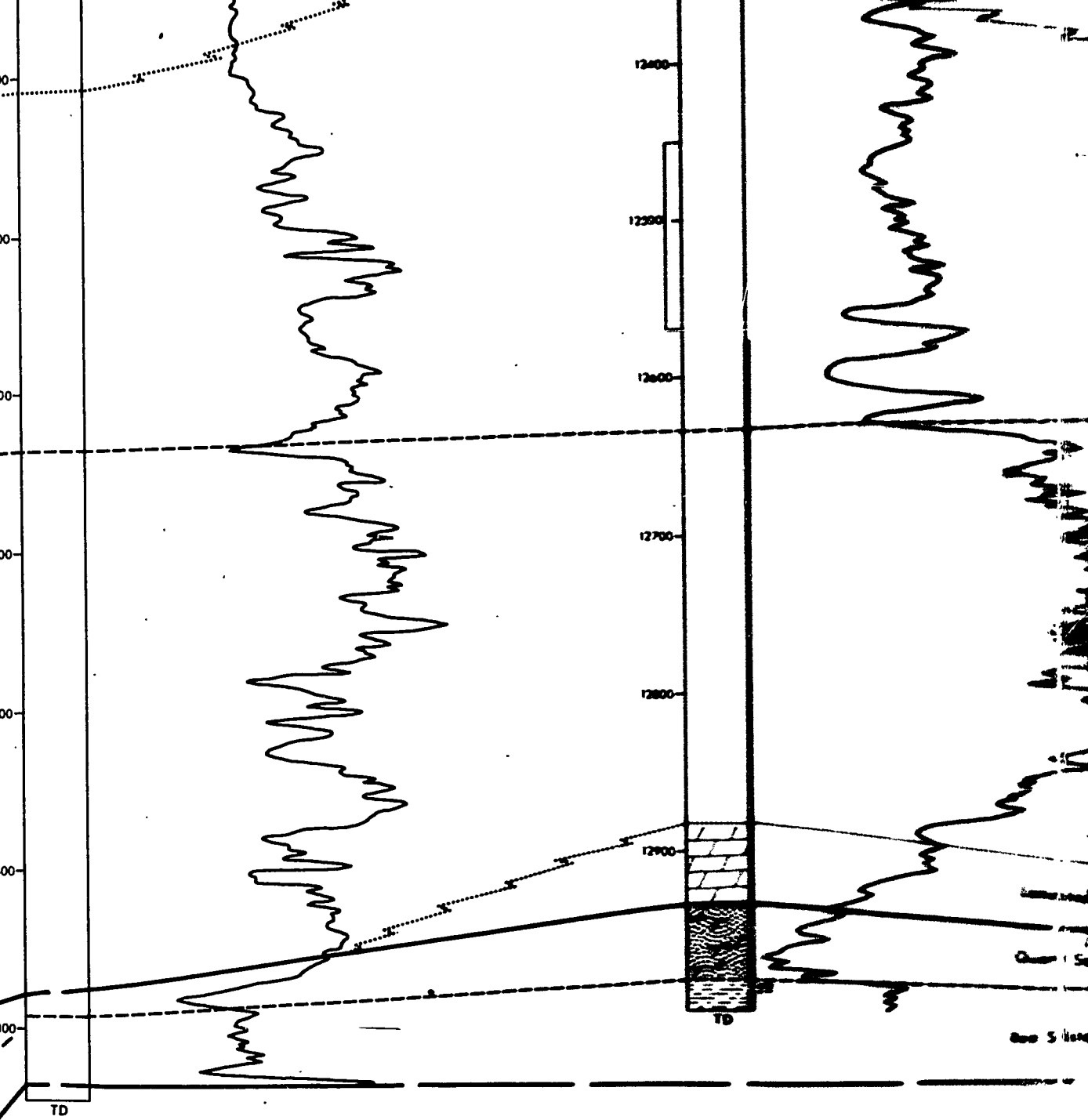
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Pelmicrite Facies

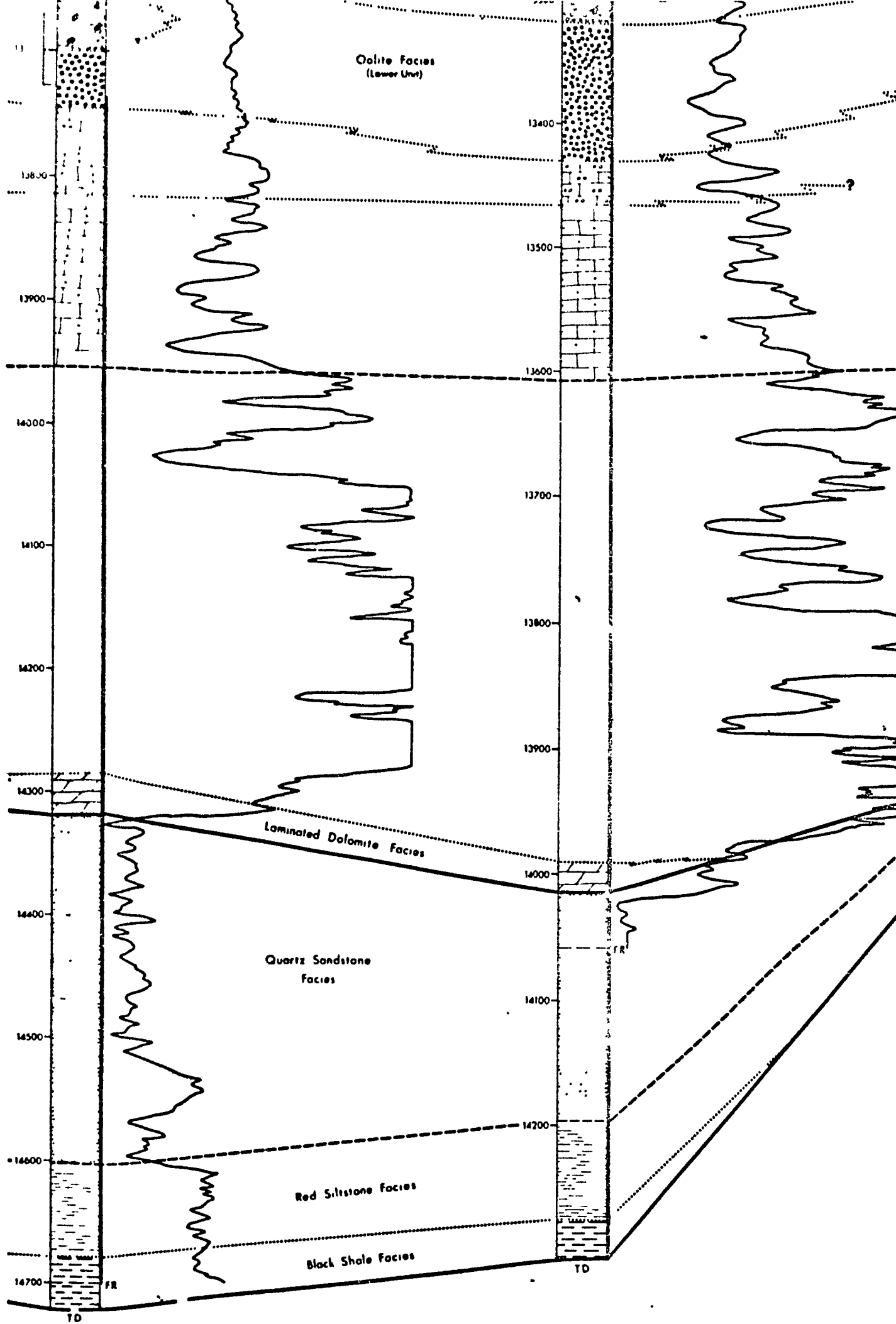
Superficial Oömicrite Facies

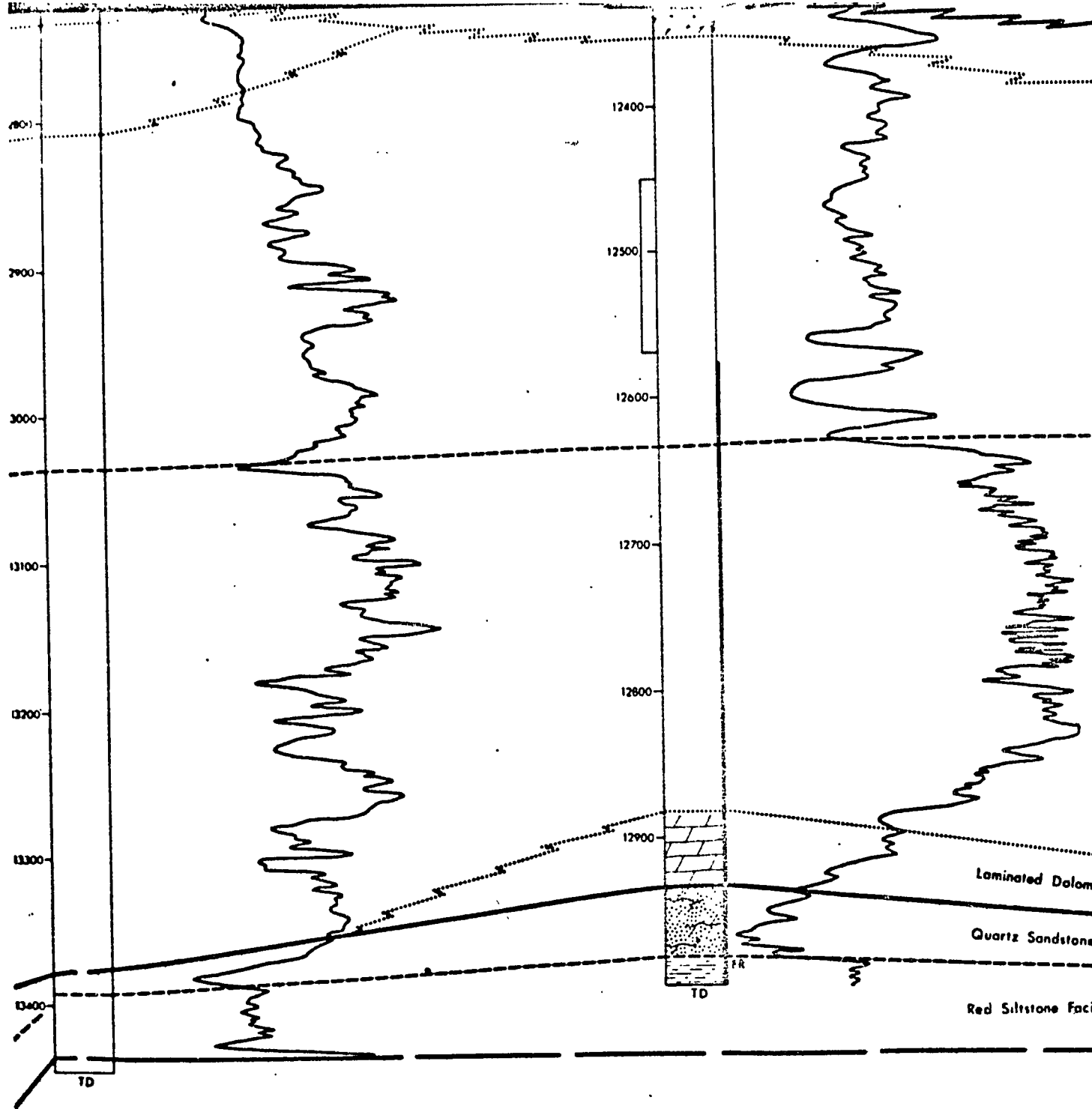
Pelletoidal Micrite Facies

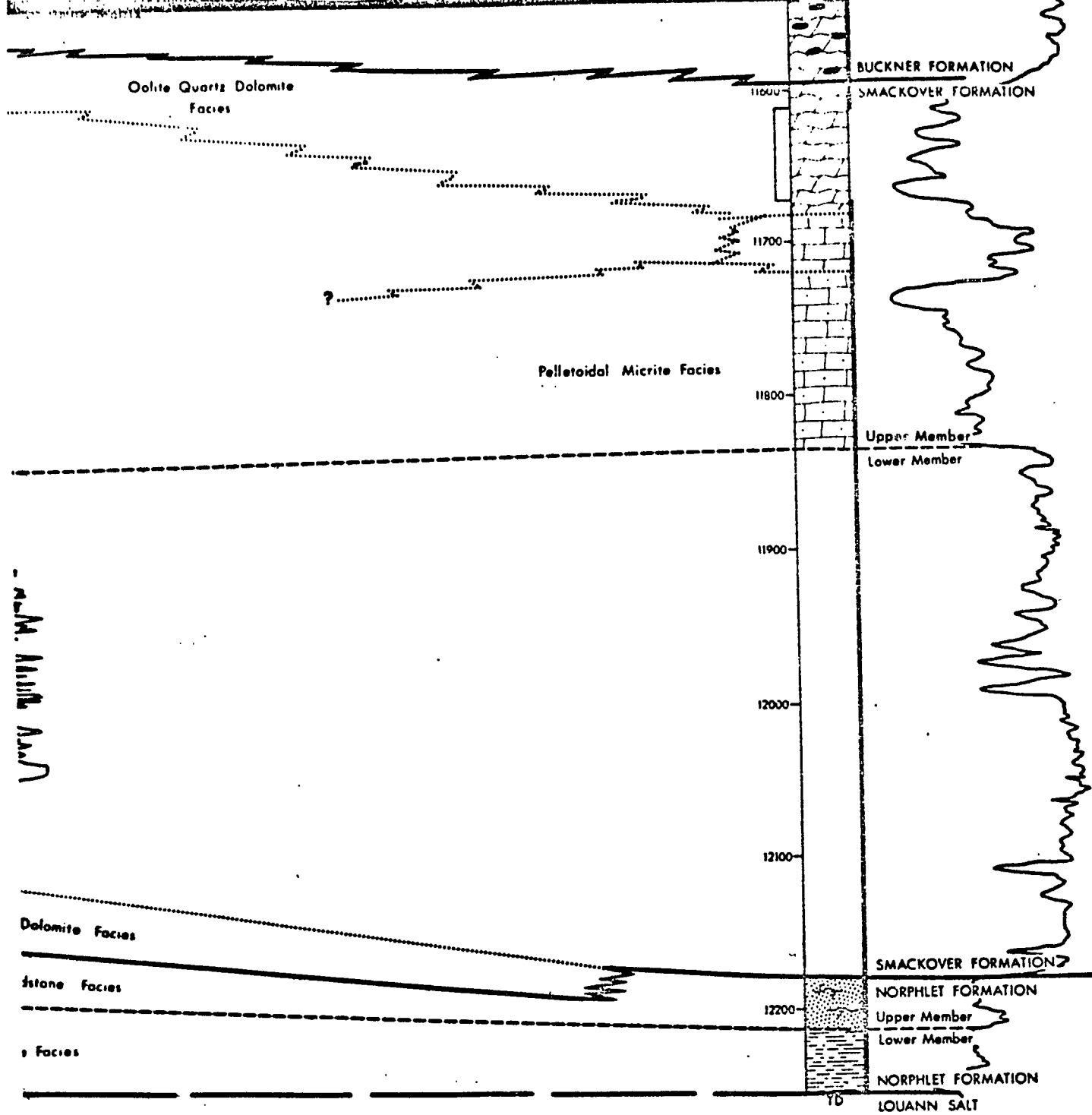
Dolomitic Micrite



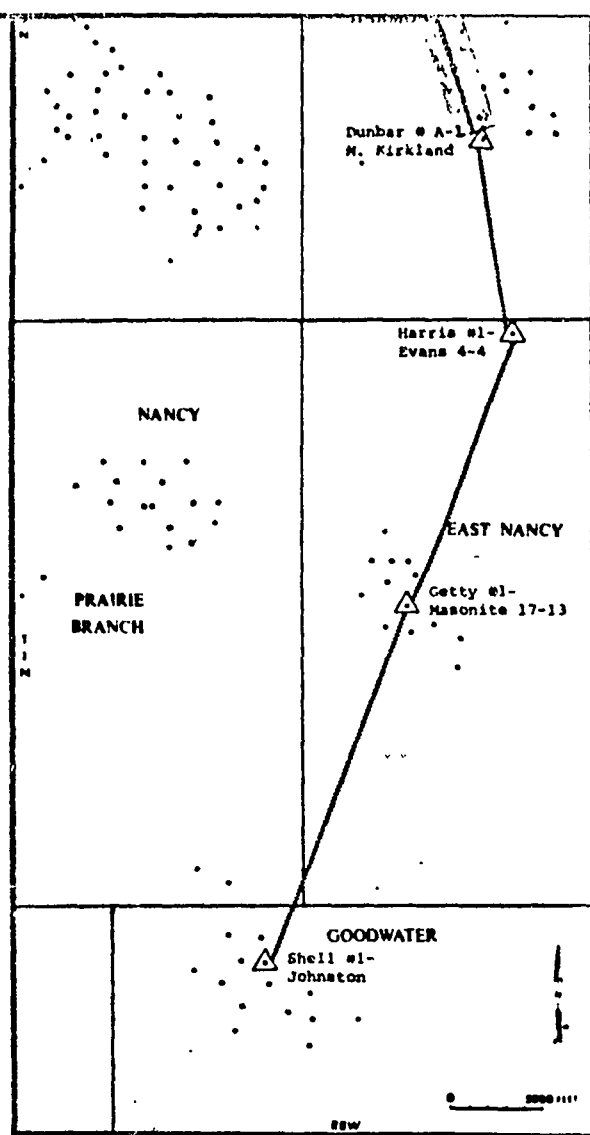












Buckner Formation



Nodular Anhydrite in  
Dolomite Matrix



Pelletoidal Micrite



Superficial Oolomite



Palmicrite Facies



Oolite Facies



Oncalitic Superficial



Oolite-Quartz Dolomite  
Facies

Upper Member, Smackover Formation

14100

Depth from  
derrick floor

Drill c

14100  
Depth from  
derrick floor

# LITHOFACIES

Buckner Formation



Nodular Anhydrite in  
Dolomite Matrix



Pelletoidal Micrite Facies

Upper Member, Smackover Formation



Superficial Oolomite Facies



Palmicrite Facies



Oolite Facies



Oolitic Superficial Oolite Facies



Oolite-Quartz Dolomite  
Facies

Lower Member,  
Smackover Formation



Dolomitic Micrite



Laminated Dolomite  
Facies

Norphlet Fm.



Black Shale Facies



Red Siltstone Facies



Quartz Sandstone  
Facies

## BOUNDARY LINE EXPLANATION

———— Formation Boundary

- - - - - Member Boundary

..... Facies Boundary

# PLATE VI